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ANTENNA PATTERN RANGE
TEST EQUIPMENT

Final Technical Report

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ANTENNA PATTERN RANGE TEST EQUIPMENT

by

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Final Technical Report

Contract No. NAS-8-11521

ADVANCED TECHNOLOGY CORPORATION
formerly
Electronic Communications, Inc.
Research Division
1830 York Road
Timonium, Maryland

April 15, 1964

Prepared for

George C. Marshall Space Flight Center
Huntsville, Alabama

ABSTRACT 20686 A

The purpose of this contract was to design and develop a high resolution bistatic radar to resolve antenna pattern ambiguities. The work was divided into two phases. The first was a study phase to determine the feasibility of designing a system to detect the presence of reflections on the antenna pattern range and to select the frequency range of operation. Upon approval of a proposed design, phase two was initiated to design, develop, and fabricate the complete system.

The test set is a high resolution, bistatic radar operating at S-band. The range of a reflection is given by the time delay between the direct path pulse and the reflected pulses. The equipment is capable of detecting reflections from distances of 4 feet to 150 feet relative to the direct path. The test set contains six units and cabling for installation.

Author

TABLE OF CONTENTS

1. INTRODUCTION

The Statement of Work in the contract required that appropriate test equipment be provided to resolve any antenna pattern range ambiguities. These ambiguities may arise from reflections by the ground, nearby obstacles, or from the model on which the antenna is located. The test equipment must be capable of detecting these reflections from distances of 4 to 150 feet relative to the direct path if they are of sufficient magnitude to interfere with the true pattern. The frequency range was to be between 2.0 and 75 Gc.

The work was divided into a study and a design phase. The study phase consisted of determining the feasibility of detecting the presence of reflections on an antenna pattern range and the displaying of the distance of such reflections. The study also included experimental verification of a design concept. Prior to initiation of the detail design concept, the proposed technique had to be approved by the Contracting Officer's authorized representative.

The second phase was the design, development, fabrication and testing of the completed system.

The work on this contract was to be completed in eight months. A forty-five day extension to this eight month period was granted because of administrative and equipment procurement delays.

2. INVESTIGATIONS

2.1 Phase I

2.1.1 Proposed System

The purpose of this contract was to develop a technique to resolve pattern range ambiguities and to identify such ambiguities occurring at ranges of 4' to 150' (see Figure 1). This bistatic radar configuration (Figure 1) permits the measurement of the time difference between the direct signal and the reflected signal (Figure 2). The path difference is

$$\Delta D = (D_r + D_t) - D = A - D .$$

The reflected path A may be determined since distance D is known. A path of constant A will generate an ellipse about points R and T. This ellipse when rotated about the major axis (axis through R and T) will generate a prolate spheriod. A measurement of path ΔD will place the target reflection on some prolate spheriod.

Figure 3 shows the curves generated by surfaces $\Delta D = 2'$ and 10' on a 150' antenna range. The bistatic system will not be capable of resolving reflections occurring on, or near, the direct line connecting the source and model antennas. The smallest ΔD will be governed by the shape of the transmitted pulse. Figure 3 also shows the 3 db beamwidths of 29 db and 20 db gain transmit antennas.

To permit the ±2 foot range resolution, a nanosecond pulse width radar was selected. Figure 4 is a block diagram of the proposed system.

Three major problems that arise in considering this system are 1) the generation of a nanosecond pulse with low sidelobe levels, 2) sufficient rf bandwidth, and 3) a broadband sensitive detector. Other problems to consider are the rise times of cables, frequency dispersion in waveguides and traveling wave tubes, and impedance matching to prevent ambiguous signals from arising from within the system.

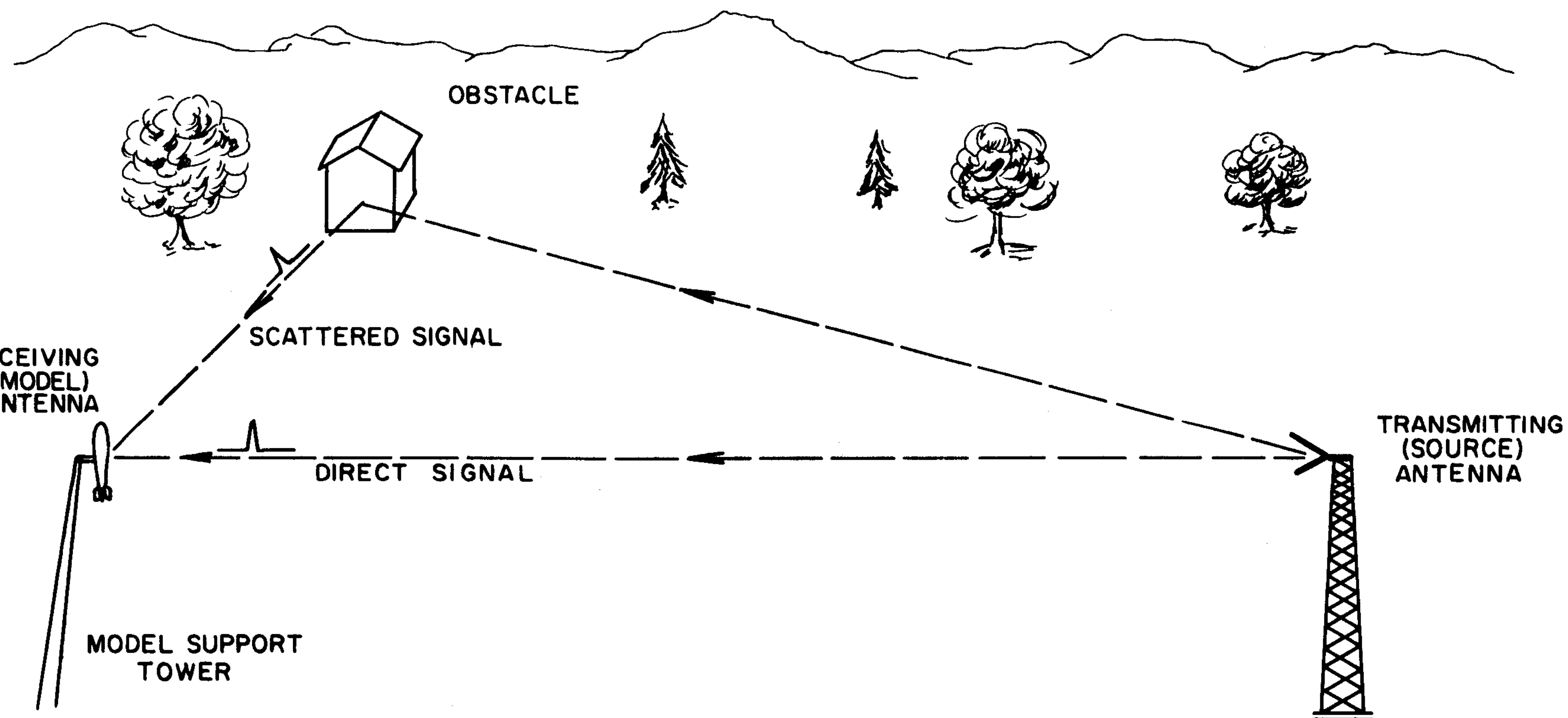


FIG. 1 – BISTATIC CONFIGURATION FOR DETERMINING REFLECTIONS IN A SCALE MODEL ANTENNA RANGE

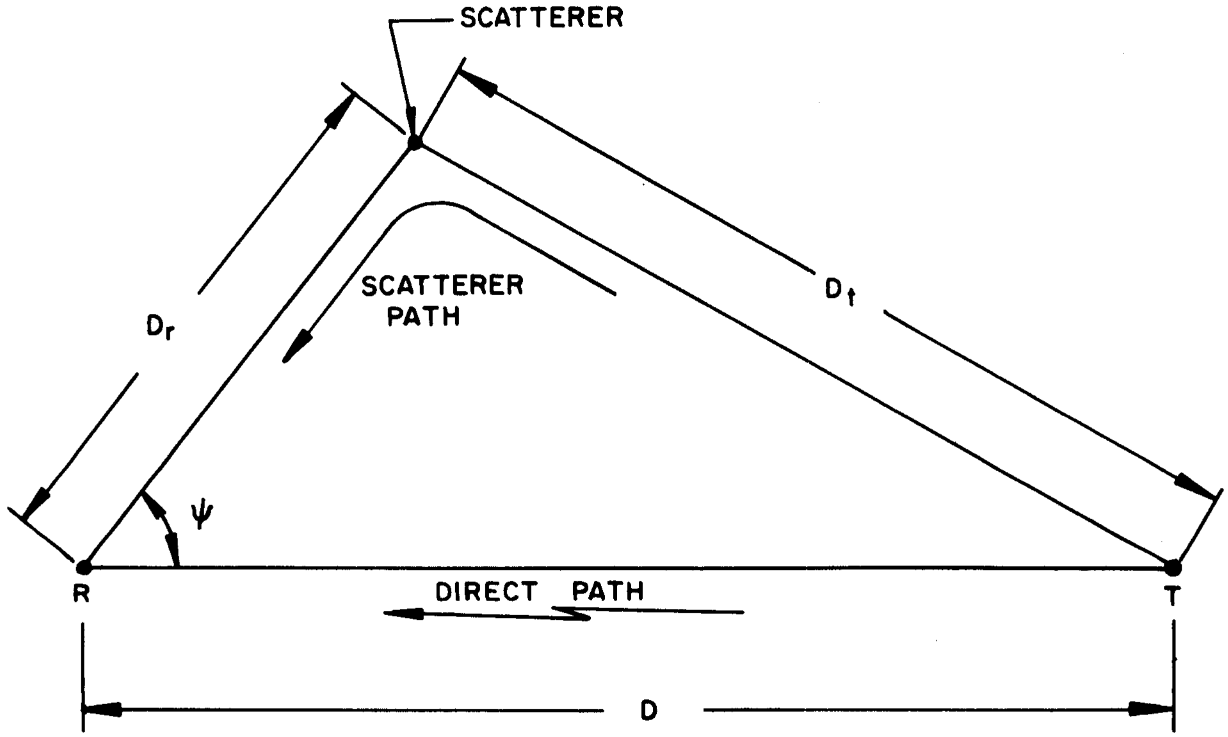


FIG. 2 -BISTATIC GEOMETRY AND NOMENCLATURE

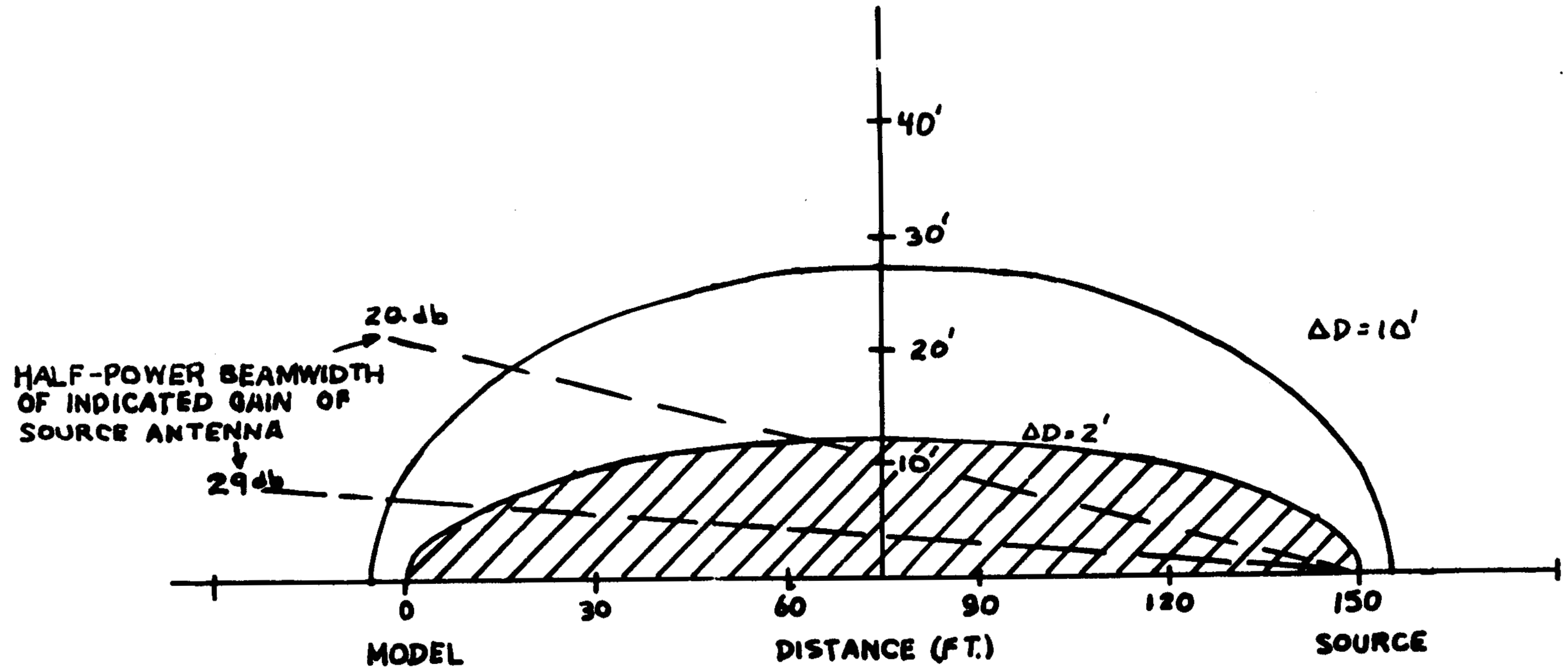


FIG. 3. - CONTOURS OF CONSTANT ΔD, FOR 150' RANGE SEPARATION

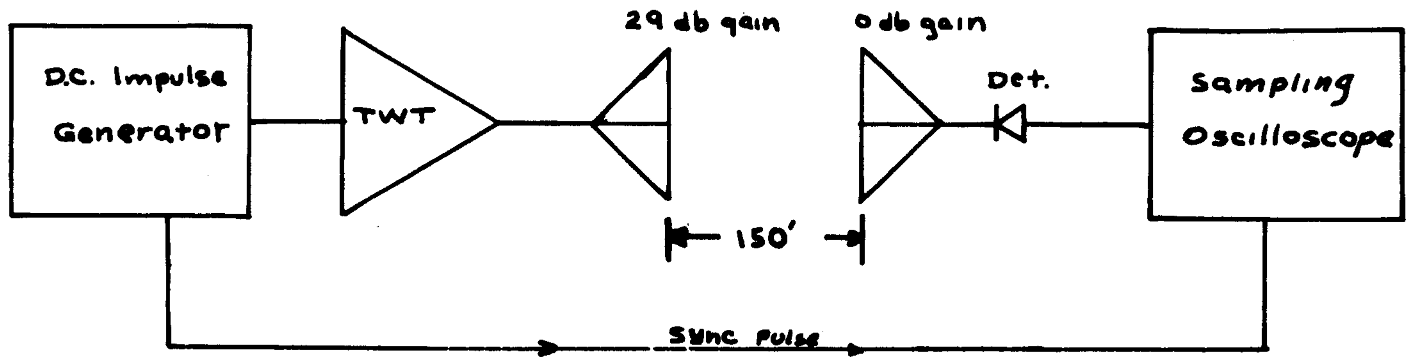


FIG. 4-. PROPOSED SYSTEM BLOCK DIAGRAM

2.1.2 Pulse Generators

The pulse generator must provide a dc pulse with a very short rise time. The shorter the rise time, the higher the energy content in the microwave region. This pulse is fed through a bandpass filter to extract the desired band of microwave frequencies. If the pulse shape is known, the power in a particular frequency region can be determined by Fourier analysis.

Several short pulse generators were evaluated for this application. A few of the electrical requirements were:

a) less than 0.25 nsec risetime

b) as high a pulse repetition rate as possible – at least 700 pps

c) sufficient output power for a medium power TWT

d) pulse widths less than 1.0 nsec

e) pulse widths of near 1 μsec are permissible if 0.25 nsec rise and fall times were available.

If the fall time of the pulse is identical to the rise time, a second output pulse from the filter would be obtained from each input pulse. This would effectively double the pulse repetition rate. The fall time is usually slightly longer than the rise time therefore the second pulse occurs but at a lower power level. For optimum results the pulser should generate a pulse with less than 1.0 nsec base width and with as high a prf as possible.

2.1.3 RF Bandwidth

Fourier analysis of an output pulse with a rise time of less than 0.5 nsec shows the presence of frequencies with reasonable amplitude from dc to greater than X-band in a pattern approximating a $\sin x/x$ distribution. For a one nanosecond pulse width, an rf bandwidth of 1 Gc is required. A bandpass filter arrangement was utilized to obtain the required bandwidth. This filter arrangement consisted of a 3 db hybrid, a section of waveguide, and a TWT.

2.1.4 Detector

Video detection of nanosecond pulses requires a broadband detector. For a one nanosecond pulse width, a one gigacycle bandwidth is required since bandwidth is inversely proportional to pulse width.

Preliminary measurements were made on a voltage doubler detector technique in waveguide. Impedance matching became a problem and the voltage doubler technique was dropped in favor of a single diode mounted in waveguide. The design and fabrication was completed for a broadband match using a single diode in waveguide between 2.2 and 4.0 Gc. Similar units were fabricated at S- and X-bands. Coaxial type detectors were compared to the waveguide unit and were found to have similar electrical characteristics. Coaxial units tested were the AEL Model 240B (2.0-4.0 Gc) and the ECI in-line type detector.

2.1.5 Laboratory Feasibility Measurements

Initial laboratory measurements were made by feeding an S-band antenna directly with a nanosecond wide dc pulse. The frequencies above the waveguide cutoff (pass band) of the antenna were radiated. Below cutoff the energy was reflected back toward the generator. A tuning stub was utilized at the antenna feed for impedance matching and pulse shaping. The reflected pulse was dissipated in the lossy transmission line and coaxial attenuators. The pulse travel time in the cable is negligible compared to the pulse repetition rate, therefore it created no interference. A bistatic experimental setup was used with a TWT for RF amplification on the receive portion of the system. The detected information was displayed on a sampling oscilloscope. Measurements were also conducted at C-band and X-band. The C-band measurements did not include a TWT in the setup. Conclusions from the initial indoor measurements were that:

a) objects less than two feet apart could be resolved

b) considerable amplification is required for C-band and X-band as compared to S-band

c) the quantity of waveguide must be limited to reduce pulse dispersion

d) the loss in RG 8 A/U cable becomes excessive at C- and X-band.

Outdoor measurements were conducted at S-band and X-bands using the same setup as used indoors. The S-band measurements were taken with 120' separation between the transmit and receive elements. A standard gain horn was used for a transmitting element and an open ended waveguide was utilized for receive. For all tests, the transmitting antenna was fixed in position and only the receiving antenna was moved. The initial test was to determine if the "ground bounce" signal between the transmit and receive elements could be detected. The receive element was moved in several discrete steps in the vertical plane to ascertain this information (see Figure 5). The test results showed that the ground bounce could be detected as shown in the -15^{o} and $+15^{o}$ angular positions of the receive antenna presented in Figure 6.

Another test that was conducted outdoors was to locate a metallic plate to one side of the receiving antenna and then turn the receive element to optimize the reflected energy from the plate. The plate was then moved in two foot steps and the above process repeated (see Figure 7). From the results in Figure 8, it is possible to detect the plate out to a distance of 23' from the center line of the setup.

X-band measurements conducted outdoors utilized a 22 db gain horn on transmit and open ended waveguide for receive. A fifty foot separation between the elements was due to the reduced output of the X-band frequency component of the pulse compared to S-band (approximately 20 db down).

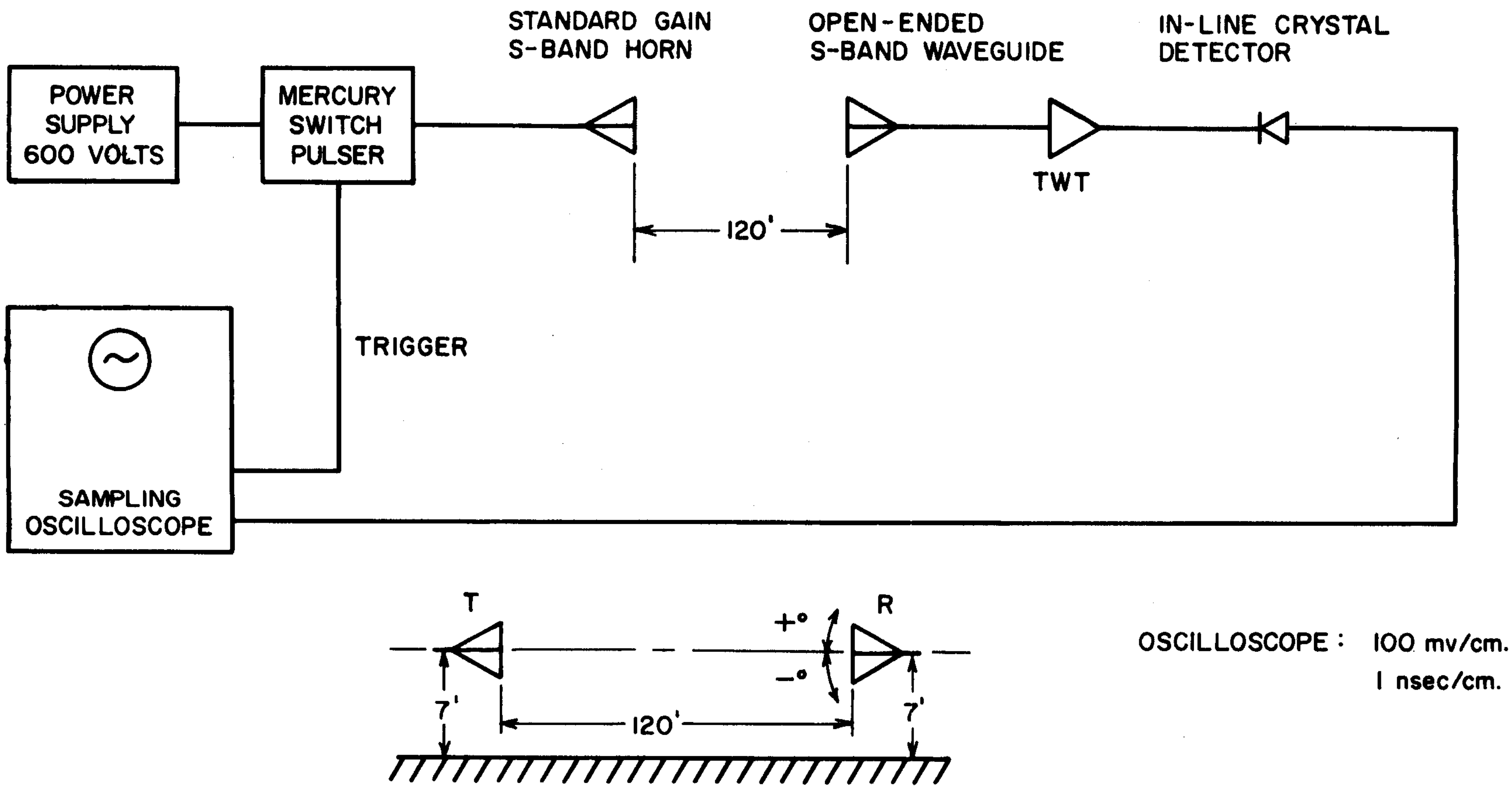
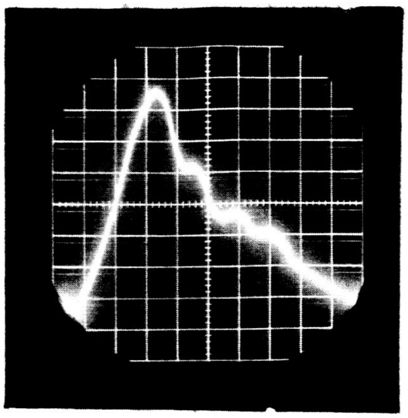


FIG. 5 - EQUIPMENT SETUP FOR S-BAND MEASUREMENTS



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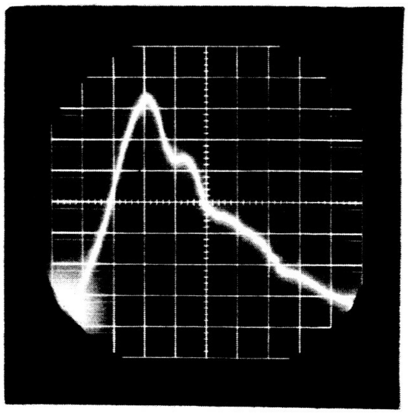

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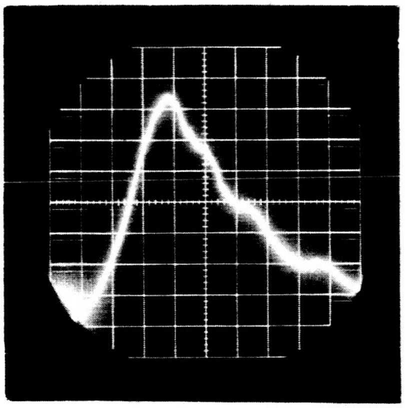
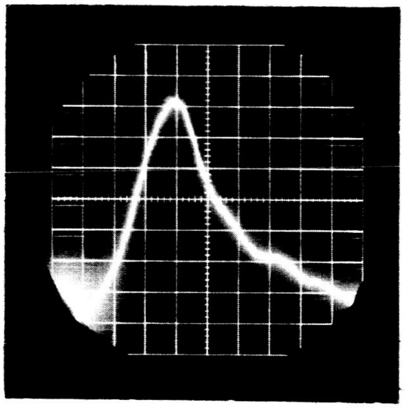


−15°



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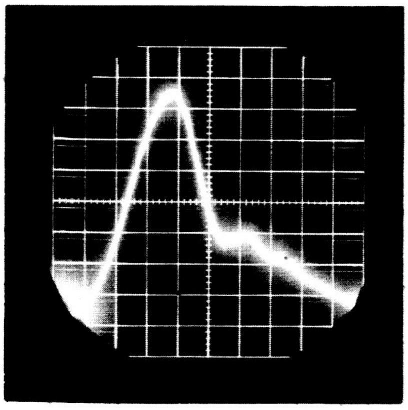

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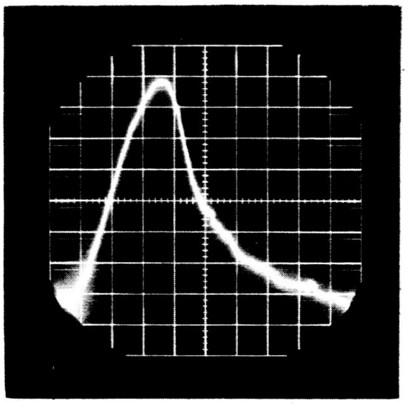


+30°

SCALES: VERT. 100 mv/cm HORIZ. 1.0 nsec/cm

RECEIVE ANTENNA (OPEN ENDED WAVEGUIDE) FOCUSED AT ANGLES ABOVE AND BELOW TRANSMIT–RECEIVE ANTENNA CENTERLINE.

FIG. 6 - RESULTS OF S-BAND MEASUREMENTS

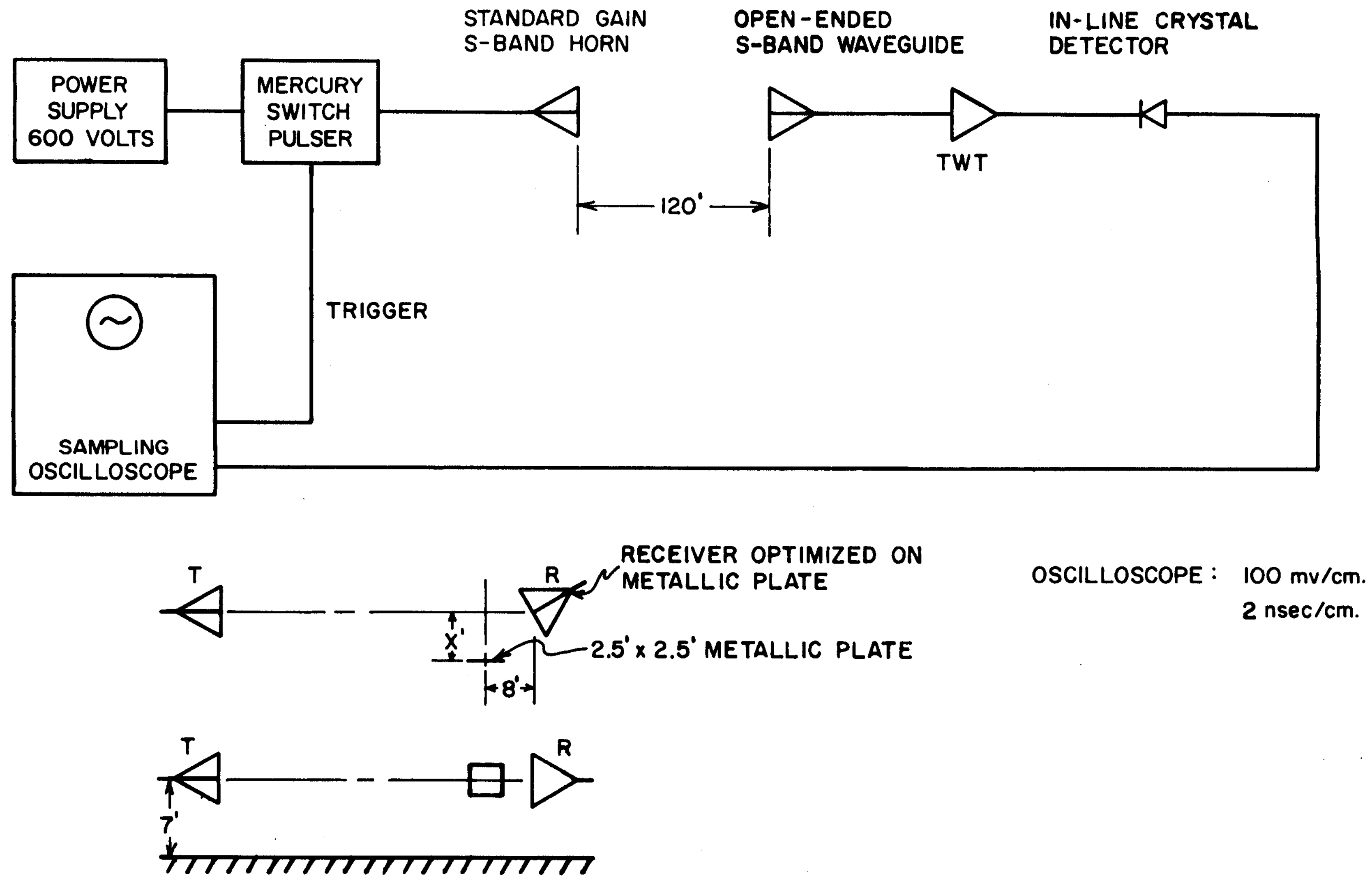
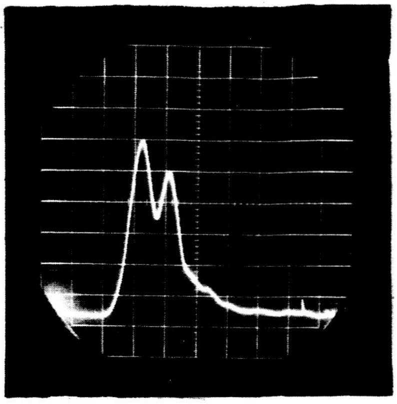
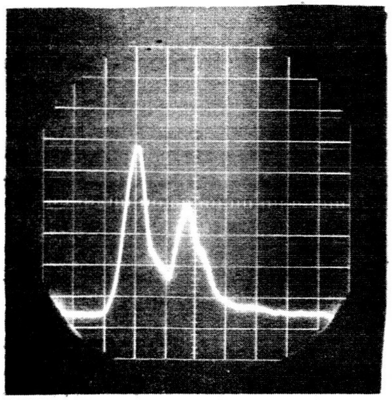


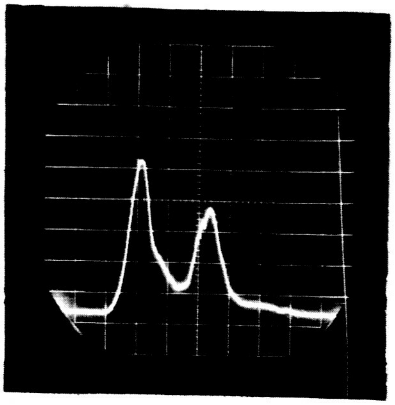
FIG. 7 - EQUIPMENT SETUP FOR S-BAND MEASUREMENTS



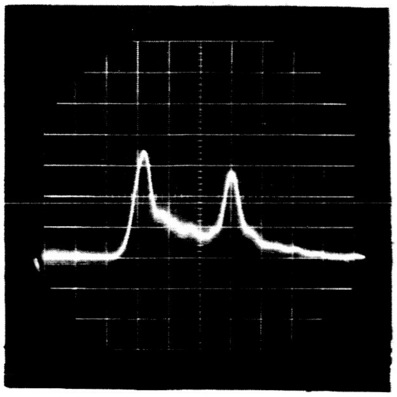
7.0 FT.



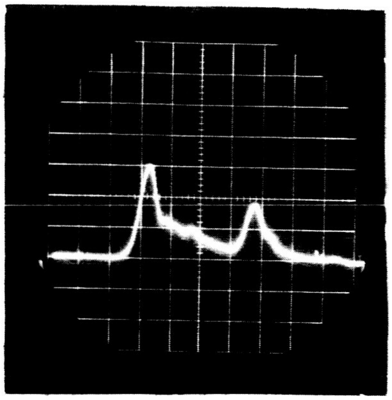
9.0 FT.



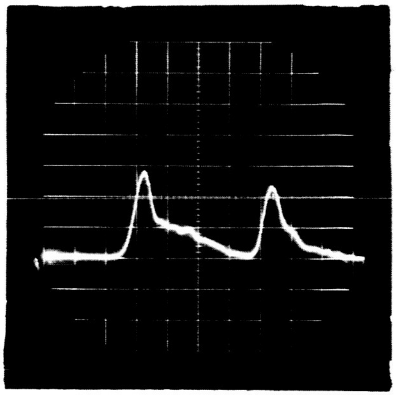
11.0 FT



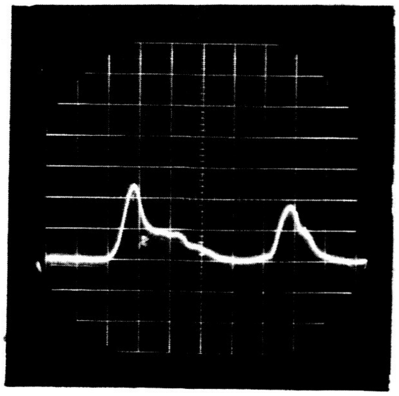
13.0 FT



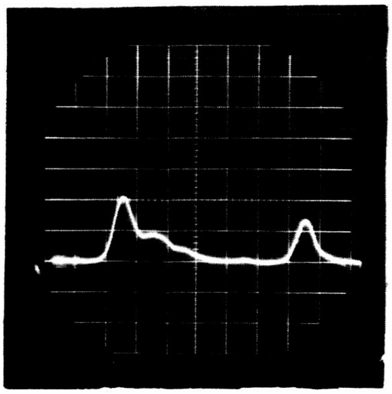
15.0 FT



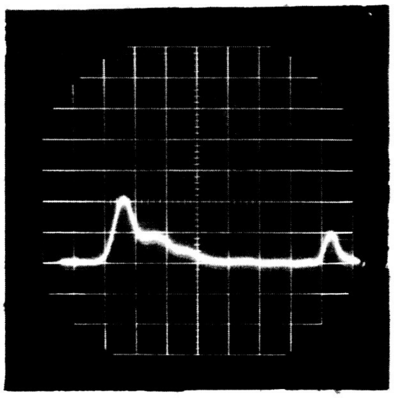
17.0 FT



19.0 FT



21.0 FT



23.0 FT

SCALE: VERT. 100 mv/cm ; HORIZ. 2.5 nano seconds/cm

RECEIVE ANTENNA FOCUSED ON 2.5' x 2.5' METAL PLATE LOCATED AT A DISTANCE FROM THE TRANSMIT-RECEIVE ANTENNA CENTERLINE. METAL PLATE IS AT THE SAME HEIGHT AS ANTENNAS.

FIG. 8 -RESULTS OF S-BAND MEASUREMENTS

A test to determine if the ground bounce signal between the receive and transmit elements would be detected was performed at X-band utilizing the same procedures as for S-band (see Figure 9). Figure 10 shows that the reflected energy from the ground is clearly noted in the -15° position as compared to the $+15^{\circ}$ position of the receiving antenna. It should be noted that the surrounding structure near the receiving antenna position had to be padded with microwave absorbing material to reduce reflections.

Measurements on a metallic plate located to one side of the receiving antenna were taken (see Figure 11) and the results are presented in Figure 12. The plate could be detected out to a distance of 6' from the antenna centerline which is approximately at the 3 db point of the transmitting antenna radiation pattern.

Conclusions from the outdoor measurements were similar to those on the indoor measurements. Of the frequencies of interest, S-band was chosen for the following reasons:

1) Considerably more energy is generated at S-band than X-band by the nanosecond pulse generator.

2) Twenty-five feet of coaxial line is required between the transmitter and antenna. Less signal attenuation in the cable is obtained at S-band compared to higher frequencies. If waveguide is used for carrying the transmitted pulse from the van to the antenna, the problem of frequency dispersion becomes serious.

2.1.6 System Power Requirements

To determine the requirements of the components in the proposed system, calculations were made of the system performance with the following assumptions:

a) The pattern range test set is to operate in the 2.0-4.0 Gc band

b) The transmitting antenna is a four foot parabolic dish with an assumed gain of 29 db at 3.0 Gc

c) An octave bandwidth receive antenna with 0 db gain has been assumed

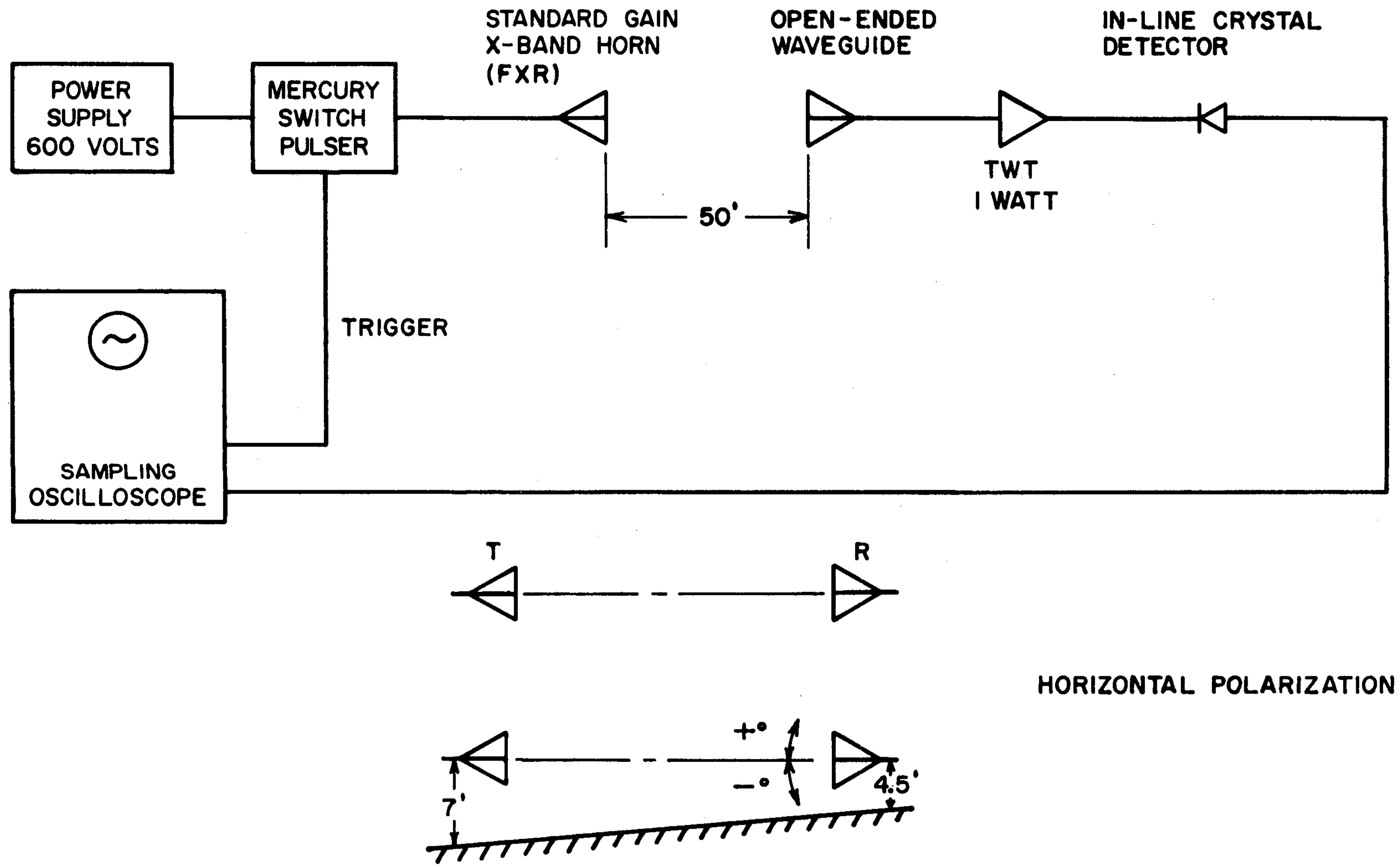
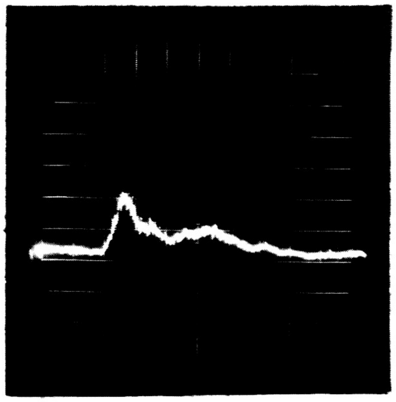


FIG. 9 – EQUIPMENT SETUP FOR X-BAND MEASUREMENTS



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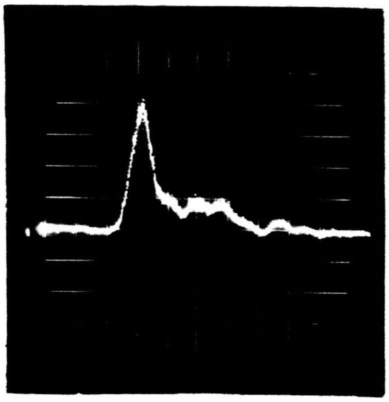
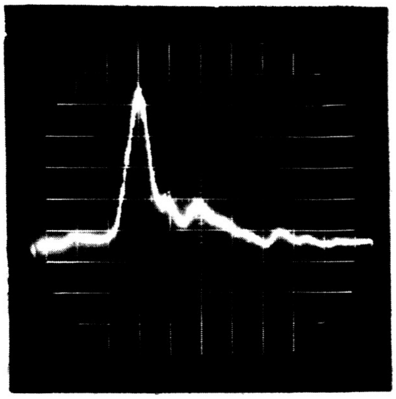


+15°



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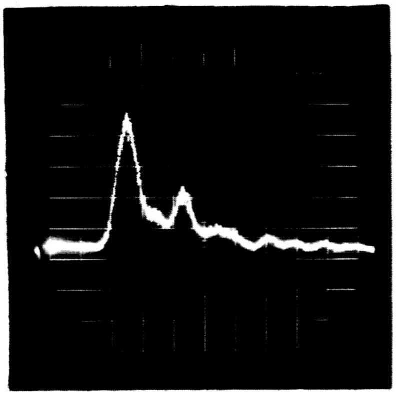
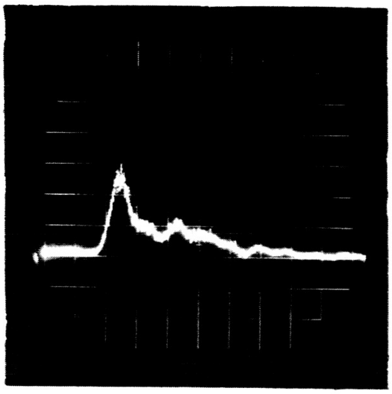


-15°



-30°

SCALE: VERT: 10 mv/cm
HORIZ: 1 nsec/cm

X-BAND BISTATIC MEASUREMENTS

HORIZONTALLY POLARIZED ANTENNAS. RECEIVE ANTENNA FOCUSED AT AN ANGLE ABOVE AND BELOW TRANSMIT-RECEIVE CENTERLINE.

FIG. 10- RESULTS OF X-BAND MEASUREMENTS

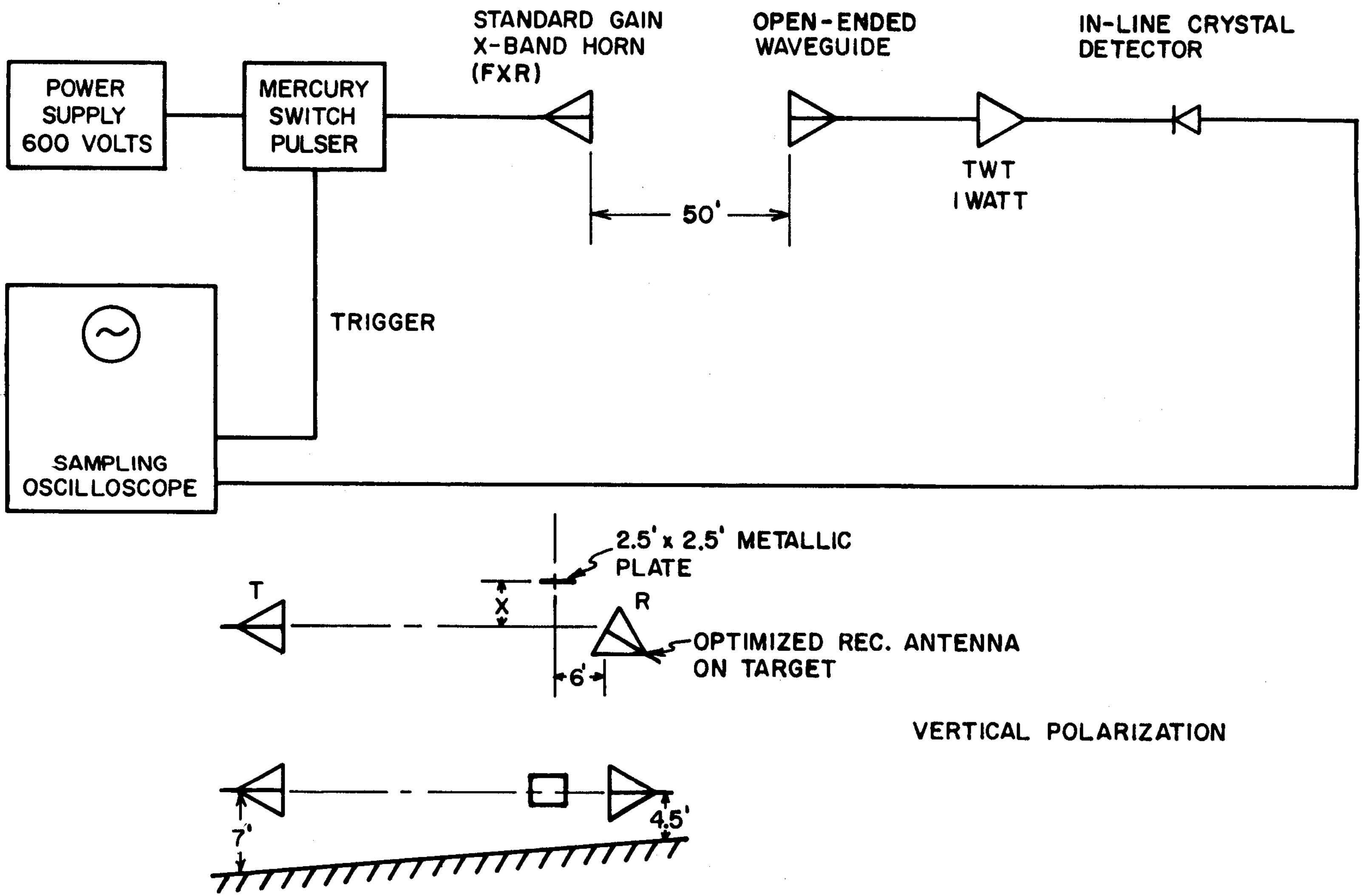
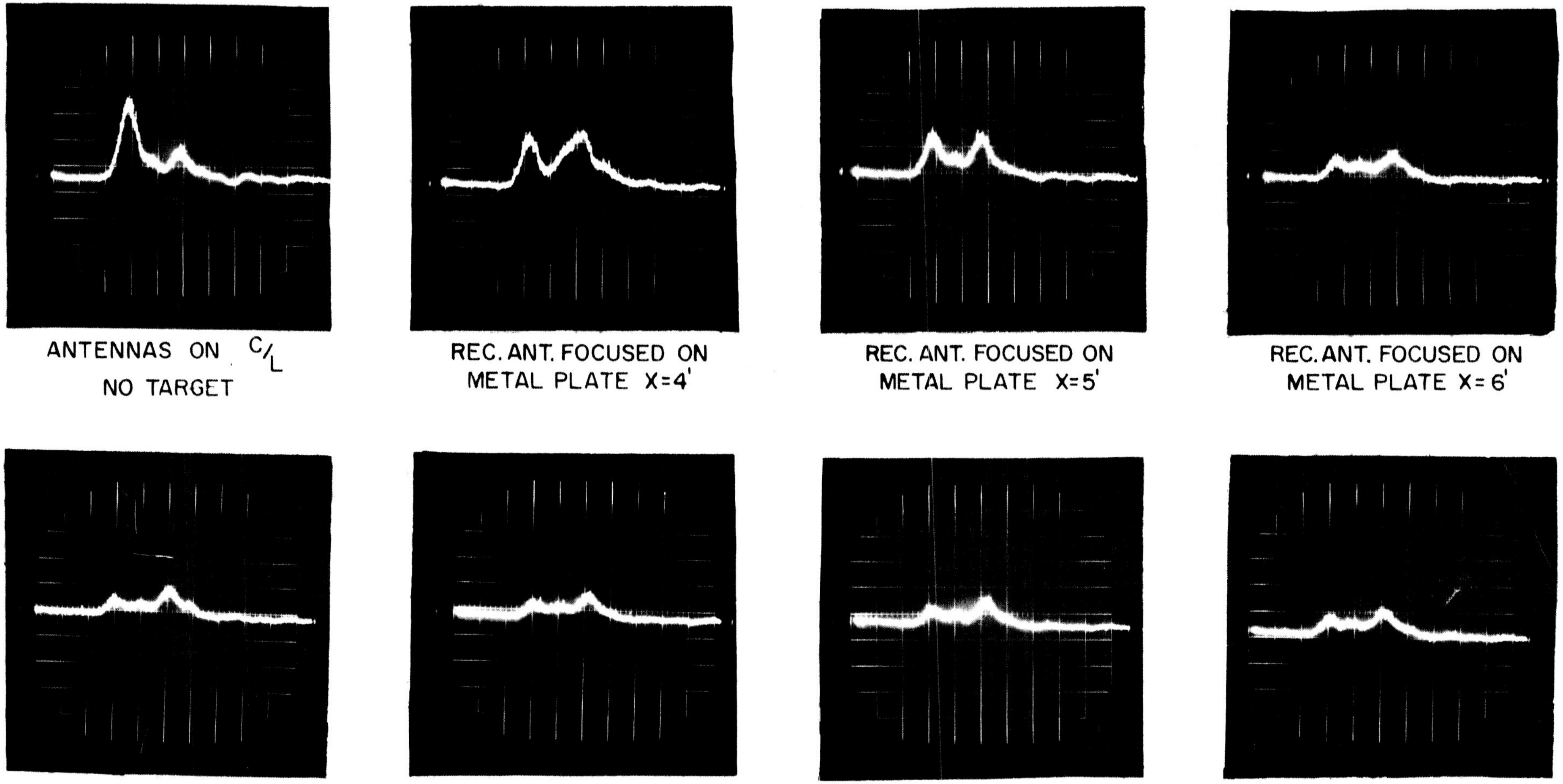


FIG. 11 – EQUIPMENT SETUP FOR X-BAND MEASUREMENTS



ANTENNAS ON $C/_{L}$
NO TARGET

REC. ANT. FOCUSED ON
METAL PLATE X=4'

REC. ANT. FOCUSED ON
METAL PLATE X=5'

REC. ANT. FOCUSED ON
METAL PLATE X=6'

REC. ANT. FOCUSED ON
METAL PLATE X=7'

REC. ANT. FOCUSED ON
METAL PLATE X=8'

REC. ANT. FOCUSED ON
METAL PLATE X=9'

REC. ANT. FOCUSED ON
METAL PLATE X=10'

SCALE: VERT. $10\ \mathrm{mv/cm}$; HORIZ. $1\ \mathrm{n\,sec/cm}$

VERTICALLY POLARIZED RECEIVE ANTENNA FOCUSED ON METAL PLATE (2.5' x 2.5') AT A DISTANCE "X" FROM TRANSMIT-RECEIVE CENTERLINE

FIG. 12 - RESULTS OF X-BAND MEASUREMENTS

d) The pattern range is 45.6 meters in extent

e) Power requirement calculations assume an optimum goal of detecting perturbations -30 db from the direct pulse

f) Optimum detector sensitivity for a 1 Gc bandwidth is approximately -33 dbm

g) The net path loss is 35.2 db (~35 db) which includes antenna gain. This is computed from the Radar equation

$$\frac{P_R}{P_T} = \frac{G_T G_R \lambda^2}{4\pi R^2}$$

The system block diagram and system power level requirements based on the above statements are presented in Figures 13 and 14, respectively. The transmission line from the TWT to the transmit antenna was assumed to be 25 foot of RG 8 A/U cable with a loss of 5 db. This would require a TWT capable of +37 dbm output. Although this indicates a 5 watt TWT would suffice, preliminary indications are that less than rated power is obtained when it is used for amplification of nanosecond pulses. A factor of 3 db has been temporarily ascertained, therefore a 10 watt package would seem satisfactory. However, this power level is recognized as marginal for the system.

2.1.7 Sampling Oscilloscopes

The general need for sampling oscilloscopes is caused by the normal gain bandwidth limitations. The state of the electronic art has not yet advanced to the point to permit direct display of fractional nanosecond low level signals. A sampling system looks at a small portion of a waveform, remembers the voltage level for a desired period and presents a display of the instantaneous amplitude, without amplifying the direct signal. The signal is sampled again slightly later in time and ultimately shows a complete display in a reconstructed form.

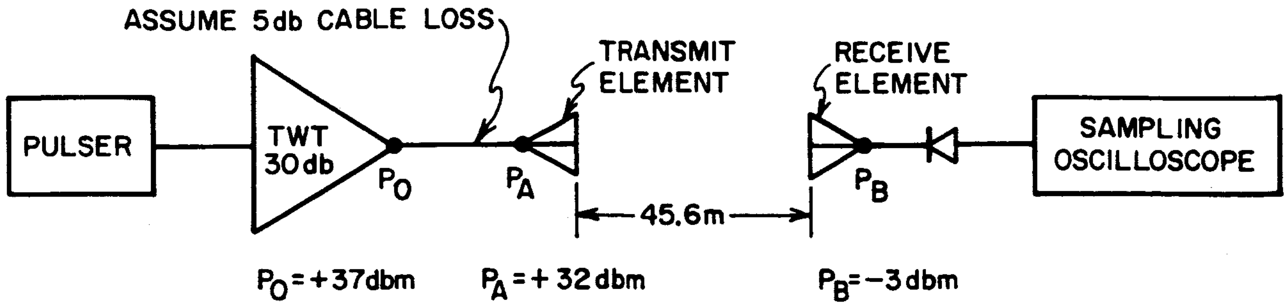


FIG.13-SYSTEM BLOCK DIAGRAM

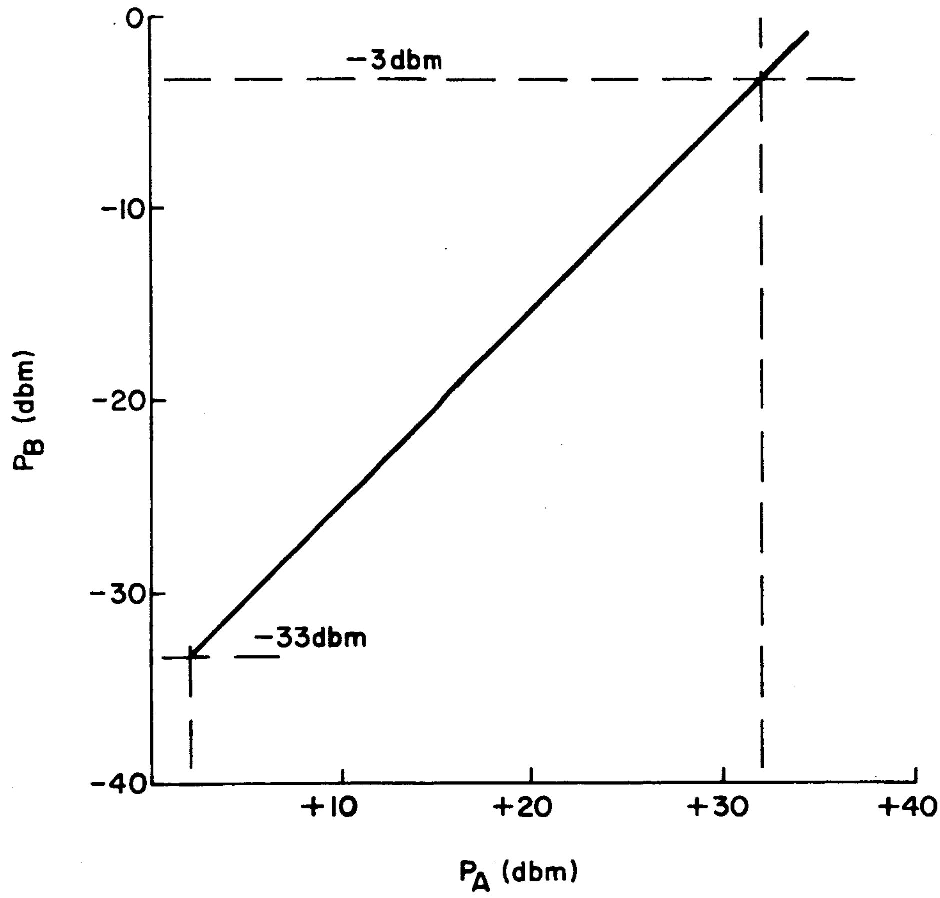


FIG.14-RESPECTIVE POWER LEVELS IN SYSTEM
$G_T = 29$ db, $G_R = 0$ db

2.1.8 Cable Effects

When using coaxial line in pulse transmission work, the term T_o is used as a measure of dielectric loss. T_o is defined as the time interval measured from the start of the output pulse to the point where $E_o = 0.5 E_{IN}$. For good cables, 10% to 90% rise time is approximately 30 T_o. Typical times for a few cables when a nanosecond pulse is applied is as follows:

	50' cable		100' cable	
	T_o	30 T_o	T_o	30 T_o
RG 8 A/U	0.09 nsec	2.7 nsec	0.36 nsec	10.8 nsec
RG 19 A/U	0.02 nsec	0.6 nsec	0.08 nsec	2.4 nsec
7/8" Spiroline	0.0025 nsec	.075 nsec	0.01 nsec	0.3 nsec

It is obvious from this there are advantages in using a special cable to improve T_o and reduce the associated losses.

2.2 Phase II

2.2.1 System Instrumentation

Upon approval of the proposed system at the end of Phase I the following equipment was purchased, adhering to all government regulations:

a) Tektronix Pulse Generator

b) ECI Pulse Shaper

c) 10 watt Alfred Traveling Wave Tube Amplifier

d) AEL S-band Detector

e) Hewlett Packard Delay Line

f) Hewlett Packard Sampling Oscilloscope

g) Interconnecting Cables and Connectors.

A block diagram of the system is shown in Figure 15. Each unit of the system will be discussed separately.

a) Pulse Generator: The Tektronix Type 110 Pulse Generator and Trigger Takeoff System is a dual instrument: a fast rise pulse generator and a trigger gating system. The fast rise pulse is

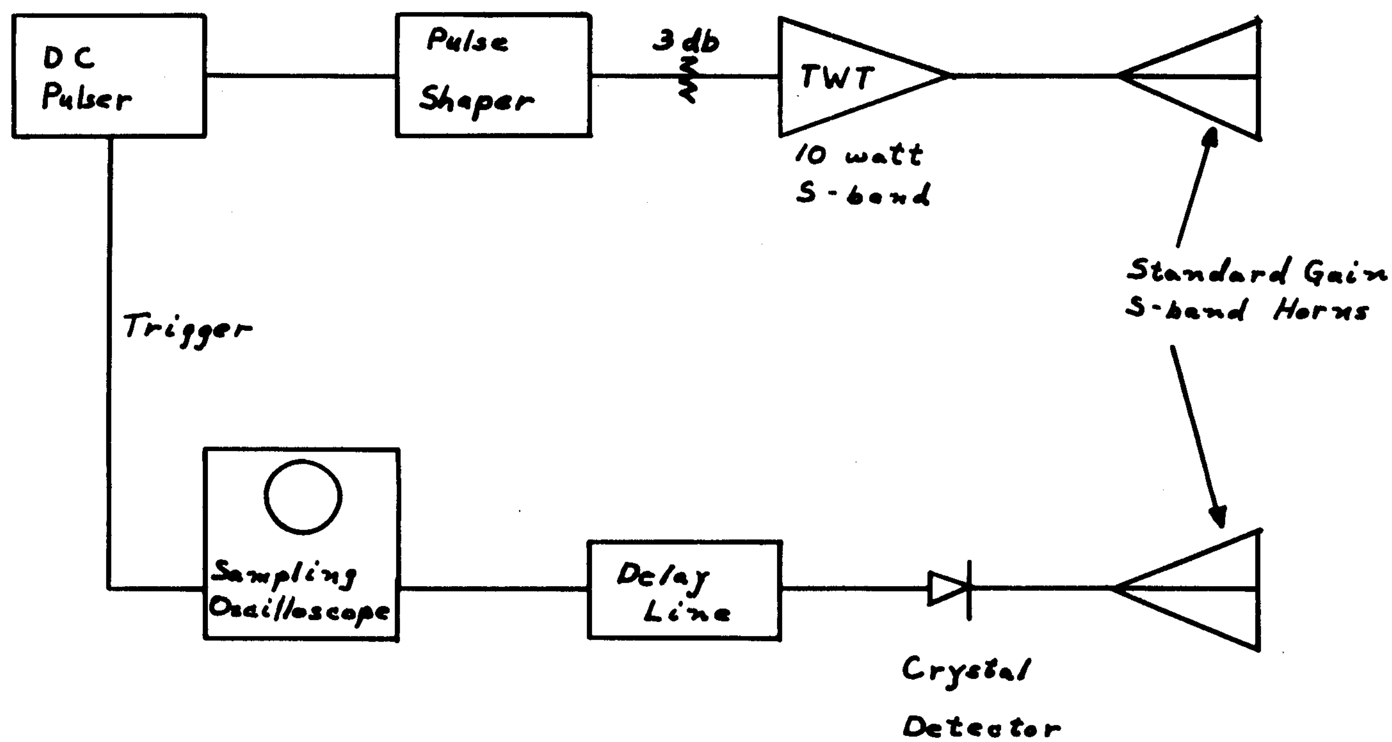


Fig. 15 - Proposed system block diagram

generated by a high repetition rate mercury relay. The trigger gating system provides an efficient method of deriving triggers from incoming signals for use in triggering external equipment. The pulse rise and fall times are less than 0.25 nsec and the pulse width is approximately 0.5 nsec. The pulse repetition rate is nearly 720 pulses per second. The pulse amplitude is variable from 0 to ±50 volts with the internal supply and from 0 to ±300 volts maximum with an external supply.

b) ECI Pulse Shaper: The purpose of the ECI Pulse Shaper is 1) to terminate all frequencies outside the 2.0-4.0 Gc passband and 2) to reduce the power level of the sidelobes. The input pulse from the pulse generator is fed to a 3 db hybrid where the passband frequencies are coupled through the hybrid while other frequencies are attenuated. The coupled energy is then fed through a monitoring tee to a varactor diode mounted in a short section of reduced height S-band waveguide. Reverse bias is then applied to the diode. The amplitude of the coupled pulse is sufficient to overcome the bias. The output of the pulse shaper is the drive for the traveling wave tube amplifier.

c) Traveling Wave Tube Amplifier: The TWT is used to amplify the low powered S-band nanosecond pulse at the output of the ECI pulse shaper. The output of the TWT is fed to the transmitting antenna.

The results of a study on readily available TWT units was the selection first of a CW type tube and second, as high an rf power output as feasible. The CW type tube was chosen over the pulse type because of the problems encountered in gating the pulse type on and off for nanosecond pulse operation. Power levels of more than +40 dbm over the 2.0-4.0 Gc band are not readily available in CW type tubes. The unit selected was the Alfred Model 5-6868 which has a 10 watt minimum saturated power output into a 50 ohm load. Front panel controls include helix and grid voltage adjustments for optimizing the pulse shape.

d) Detector: The receive signal is obtained by video detection of the nanosecond pulse. For maximum sensitivity in this broadband application the AEL type CNB 240 with an AEL 10 diode was selected. For a 1 Gc bandwidth the tangential sensitively is approximately -33 dbm.

e) Sampling Oscilloscope: The detected signal is fed through cables to the sampling oscilloscope. The sampling oscilloscope selected for this application was the Hewlett Packard 185B/187B dual trace sampling head and oscilloscope. An excellent feature of the unit is the simplicity of operation. The 187B provides a bandwidth greater than 1000 Mc. The 187B samples the amplitude at various points along an input signal instead of continuously monitoring the signal. A sample is taken each time a trigger pulse occurs and the signal is plotted point by point on the CRT of the 185B. The input signals are applied to the 187B through high impedance probes which are permanently attached to the unit. The input impedance is 0.1 megohms shunted by 2 pf. Input signals can be up to 2 volts peak-to-peak without overloading the probes regardless of sensitivity range. The probes should never be overloaded in this application since up to 10 microseconds is required for recovery. Normally, pulse levels to be encountered by the scope when used in this test set will be considerably less than the 2 volts peak-to-peak.

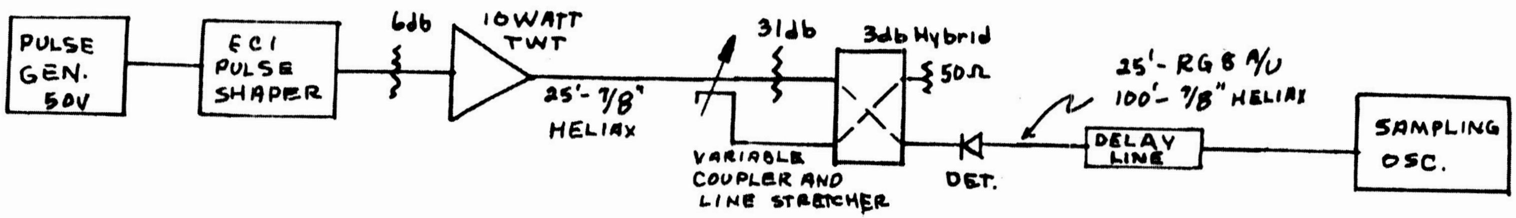
f) Delay Line: The 185B/187B oscilloscope has a finite internal delay between the time the sync circuit is triggered and the sample is taken. When triggering from the source being viewed, an external delay line must be inserted in the line supplying the vertical signal to provide a corresponding delay. The model 1100A was designed to provide this delay and to retain desirable rise time and bandwidth characteristics. The delay time provides 120 nsec delay and has a rise time between 0% and 90% at the pulse height of approximately 1 nsec and a bandwidth of approximately 1000 Mc.

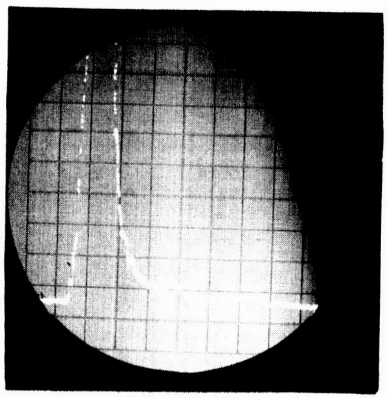
g) Cabling: A combination of RG 8 A/U and heliax cables have been employed in the system. The heliax cable is semi-flexible and is ideally suited to pulse applications. RG 8 A/U cable is used at points where added flexibility is required. The heliax cable that is used in the signal path is 50 ohm 7/8" air dielectric. A 3/8"-50 ohm heliax cable is used in the trigger path.

2.2.2 System Evaluation At ECI

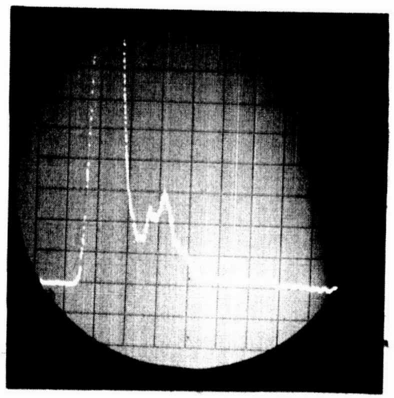
System performance has been evaluated both indoors on a simulated range and outdoors on a short pattern range. All components that make up the test set were used in the evaluation except for the 4' parabolic transmit antenna.

The first measurement was an indoor test with simulated range and controlled reflections for targets. From calculations with the radar equation, where antenna gains of 29 db and 0 db were assumed and a range of 45.6 meters was given, the received energy is 35 db below the transmitted power. This is represented in the tests by the 31 db attenuator and an additional 3 db in the directional coupler (see Figures 16-17). Just prior to the 31 db attenuator, a small portion of the signal is coupled off and delayed by a variable length line. The delayed pulse is recombined with the reference signal in the 3 db directional coupler. The reference signal represents the boresight (direct) pulse and the delayed pulse is the simulated target echo. The output is detected and displayed on the oscilloscope. Figure 16 shows the coupled pulse 10, 15, and 20 db below and 3.5 nsec after the direct path signal. When the coupled pulse is -20 db from the direct path, it is still above the minimum detectable amplitude. Figure 17 shows the coupled pulse at delays of 4, 8, and 12 nanoseconds. At 4 nsecs, the coupled pulse can be identified at a -20 db level but not as easily as at the -16 db level. A coupled pulse that is 20 db from direct path can be detected at 8 and 12 nsec delay and is also seen at a -25 db from direct path at 12 nsec delay time. The pulse occurring at

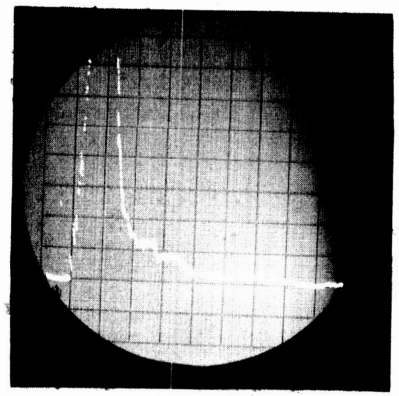




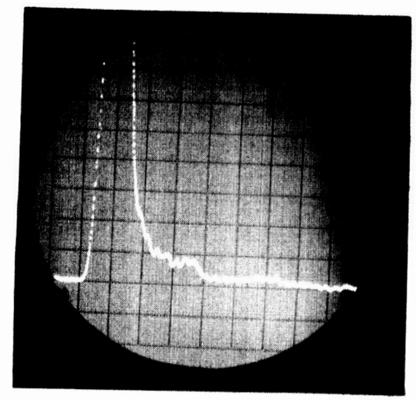
VERT: 10 mv/cm
HORIZ: 2 nsec/cm
NO DELAYED PULSE



VERT: 10 mv/cm
HORIZ: 2 nsec/cm
Coupled Pulse -10db
PULSE DELAY 3.5 nsec



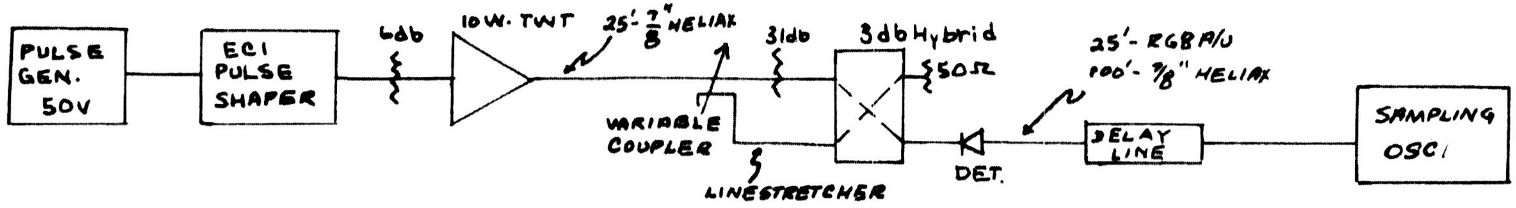
VERT 10 mv/cm
HORIZ 2 nsec/cm
COUPLED PULSE -15db
PULSE DELAY 3.5 nsec.

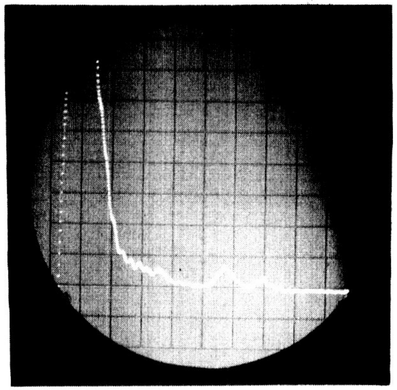


VERT: 10 mv/cm
HORIZ: 2 nsec/cm
COUPLED PULSE -20db
PULSE DELAY 3.5 nsec

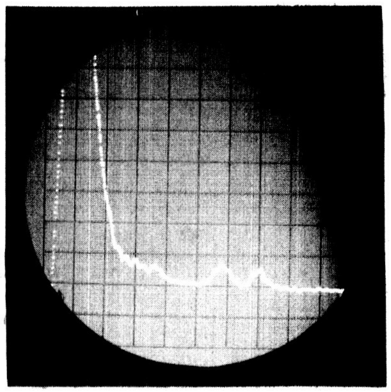
DELAYED PULSE AMPLITUDE REFERENCED TO MAIN PULSE (BORESIGHT).

FIG. 16. - INDOOR TESTS AT ECI WITH SIMULATED RANGE AND REFLECTIONS

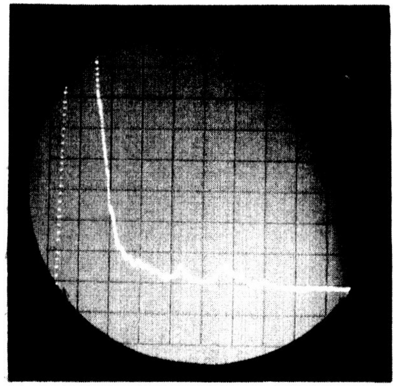




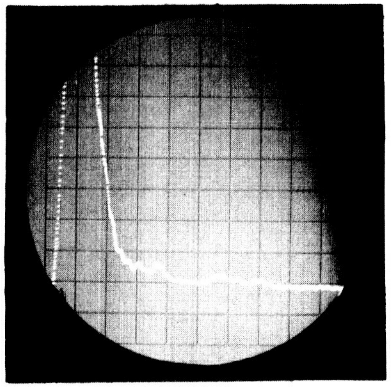
V: 20mv/cm H: 2nsec/cm
PULSE DELAY = 12 nsec
PULSE LEVEL = -25db



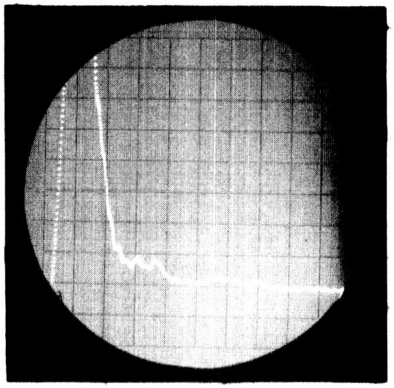
V: 20mv/cm H: 2nsec.
PULSE DELAY = 12nsec
PULSE LEVEL = -20db



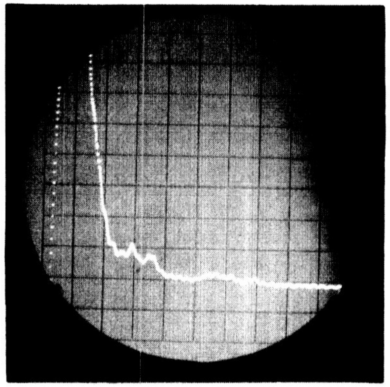
V: 20mv/cm H: 2nsec/cm
PULSE DELAY = 8.0 nsec.
PULSE LEVEL = -20db



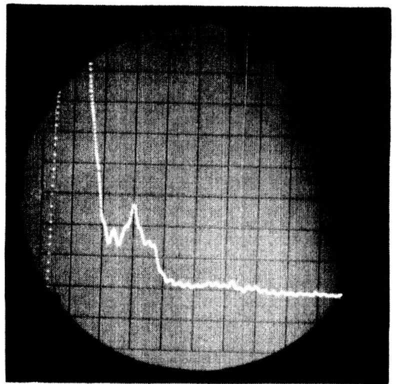
V: 20mv/cm H: 2.0nsec/cm
PULSE DELAY : 4.0nsec
PULSE LEVEL = -20db



V: 20mv/cm H: 2.0nsec/cm
PULSE DELAY = 4.0nsec
PULSE LEVEL = -16db



V: 20mv/cm H: 2nsec/cm
PULSE DELAY = 4nsec
PULSE LEVEL = -15db



V: 20mv/cm H: 2.0nsec/cm
PULSE DELAY = 4nsec
PULSE LEVEL = -10db

DELAYED PULSE LEVEL REFERENCED TO MAIN PULSE (BORESIGHT)

FIG.17.- INDOOR TESTS AT ECI WITH SIMULATED RANGE AND REFLECTIONS

10 nsec delay was found to be due to a defective connector.

The pulse shape at points within the system and the initial test on the outdoor pattern ranges are shown in Figure 18. These pictures show the response of the system at typical voltage settings on each piece of equipment. The pictures include:

1) Pulse generator dc pulse output
2) RF pulse at the output of the 3 db hybrid
3) The detected RF pulse
4) Detected RF pulse after adding the pulse shaper
5) System response with 36 db attenuation simulating range
6) System response on a 35' pattern range and using a 16 db gain horn antenna
7) System capability in resolving a reflector close to the direct pulse.

In Figure 19, the receive antenna was focused at angles 30^{o} above to 15^{o} below boresight on the 35 foot pattern range. The response from the ground (course driveway rock) is shown to be at least 20 db below the boresight pulse level.

Figure 20 shows the response to an aluminum plate 2.5' x 2.5'. This reflector is mounted on a column 7' high and was positioned at several points away from the boresight path. The receive antenna was rotated slightly when the plate was the furtherest from the centerline. The range ΔD (difference between the direct path and the reflected path) can be closely determined from the photographs. The scales are shown at 5 nsec/cm or approximately 5 ft/cm. The distances above (35', 11', 12', etc.) are approximate. An example is where x = 11', y = 12', and range is given as 35'. From this, ΔD is 6.8' and from the corresponding photograph ΔD is a little over 5.0'. Better correlation probably would be noted if the distances had been measured more accurately.

2.2.3 System Installation At M.S.F.C.

The test equipment was installed on the antenna

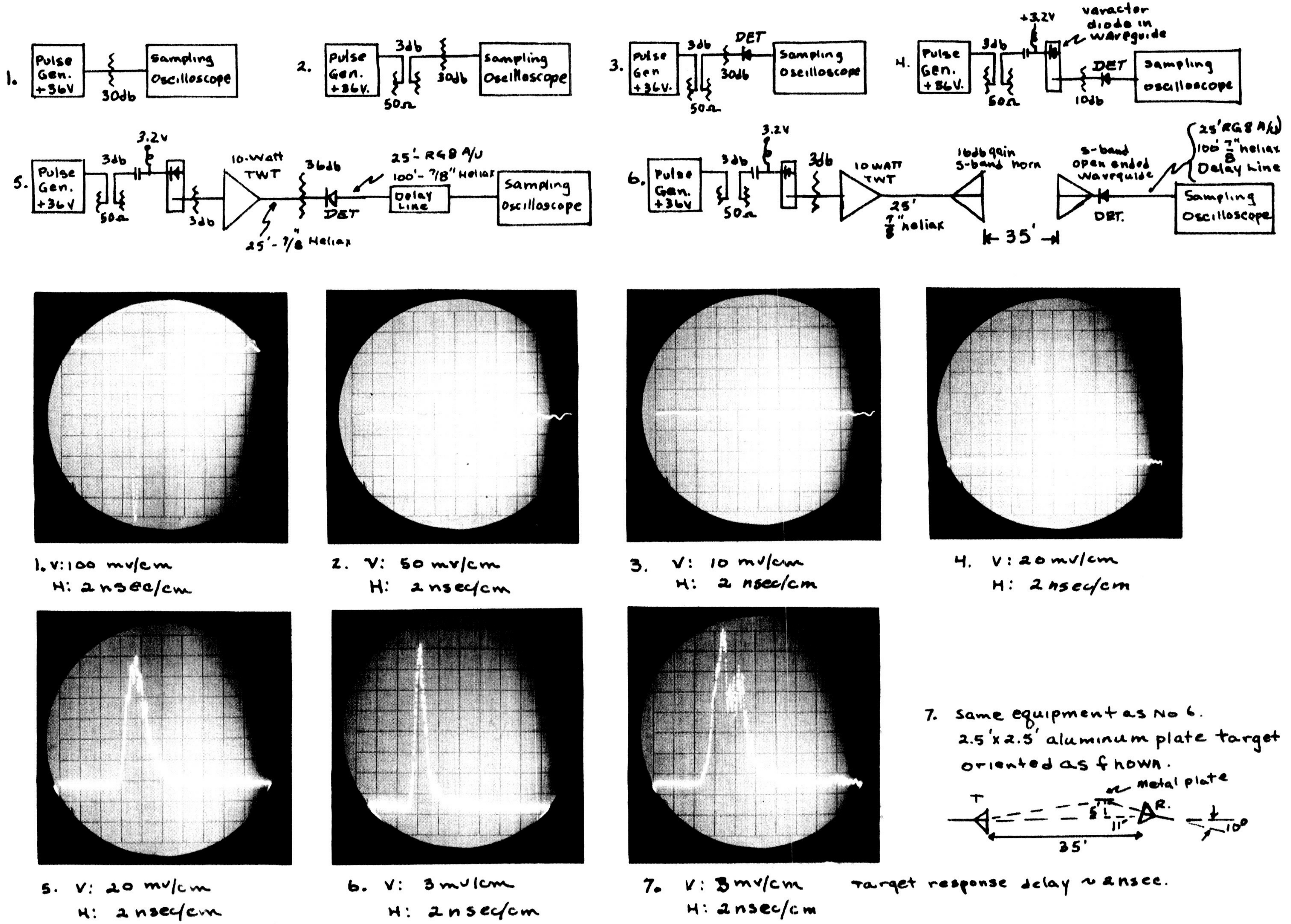
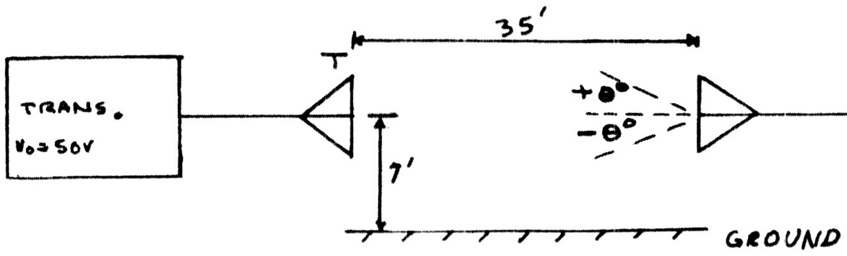
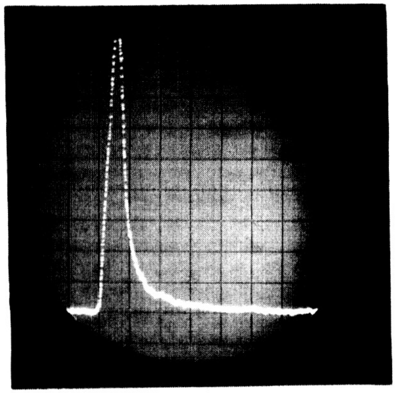
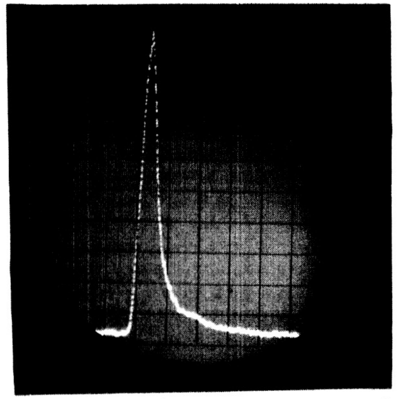


FIG. 18. – SYSTEM RESPONSE IN PRELIMINARY TESTS AT E.C.I.

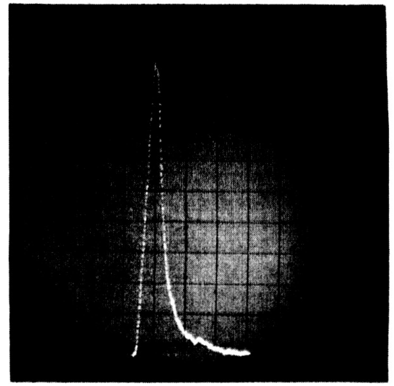




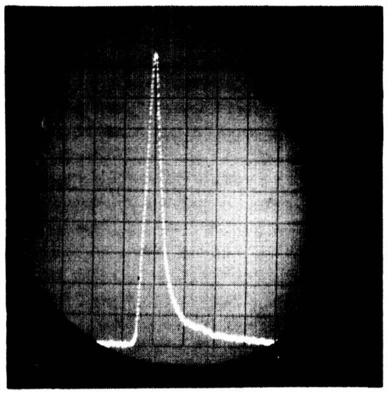
V: 3mv/cm H: 5nsec/cm
θ = 0°



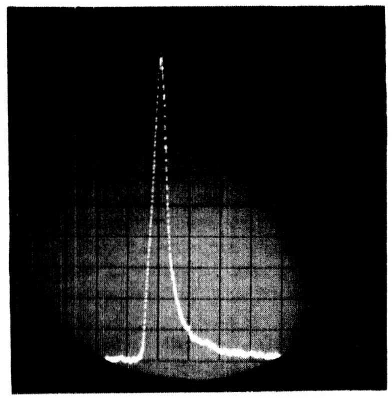
V = 3mv/cm H: 5nsec/cm
θ = -10°



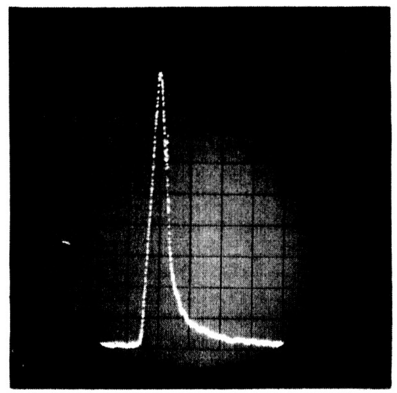
V = 3mv/cm H = 5nsec/cm
θ = -15°



V = 3mv/cm H = 5nsec/cm
θ = -20°



V = 3mv/cm H = 5nsec/cm
θ = + 15°



V = 3mv/cm H = 5nsec/cm
θ = + 30°

FIG. 19. – OUTDOOR PATTERN RANGE TESTS AT ECI

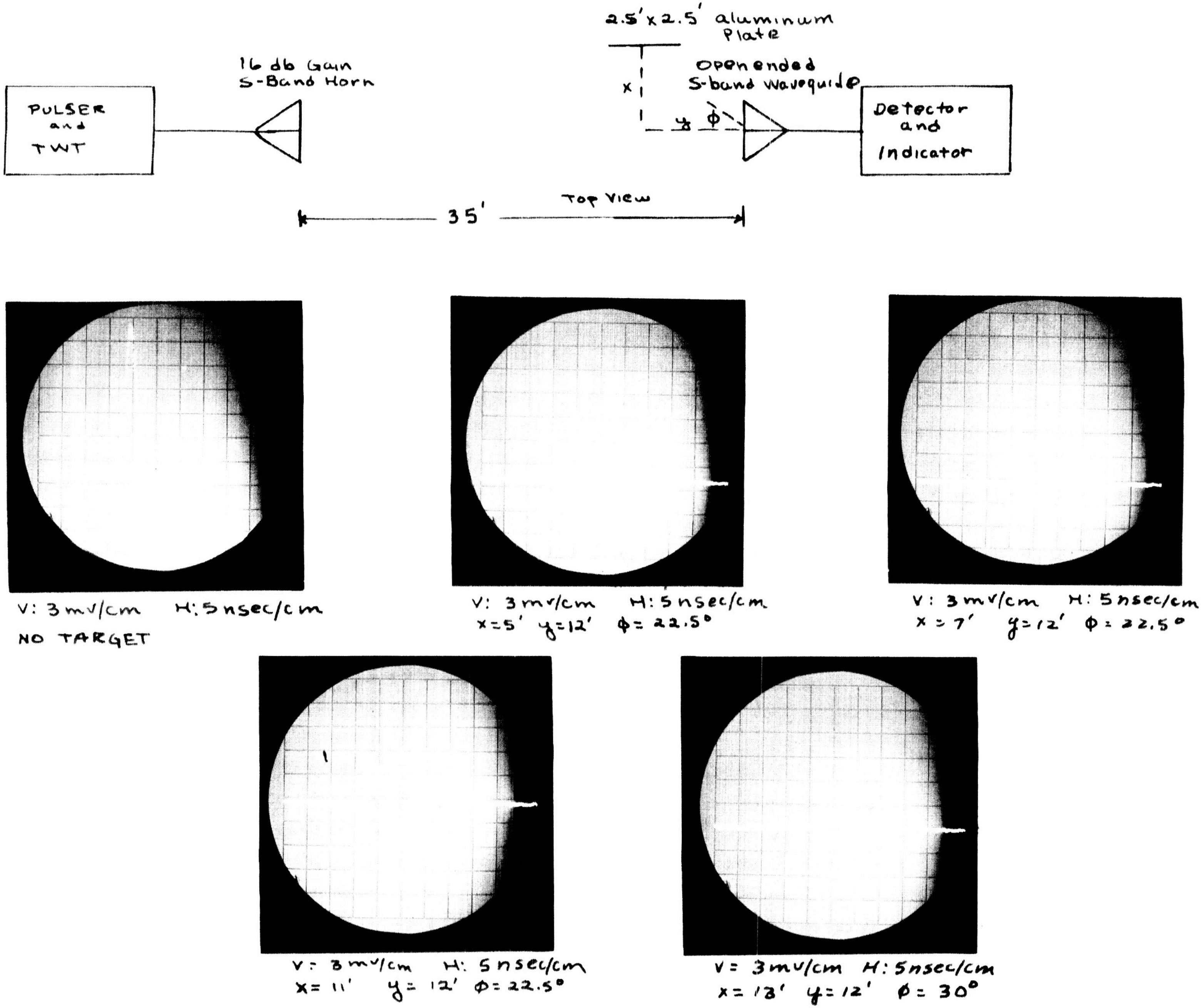


FIG. 20. - SYSTEM RESPONSE IN PRELIMINARY OUTDOOR TESTS AT ECI.

pattern range at the M.S.F.C. The equipment was designed to determine the origin of any reflections that would reduce the reliability of the pattern range. The test set equipment was located at the following parts of the pattern range (see Figure 21).

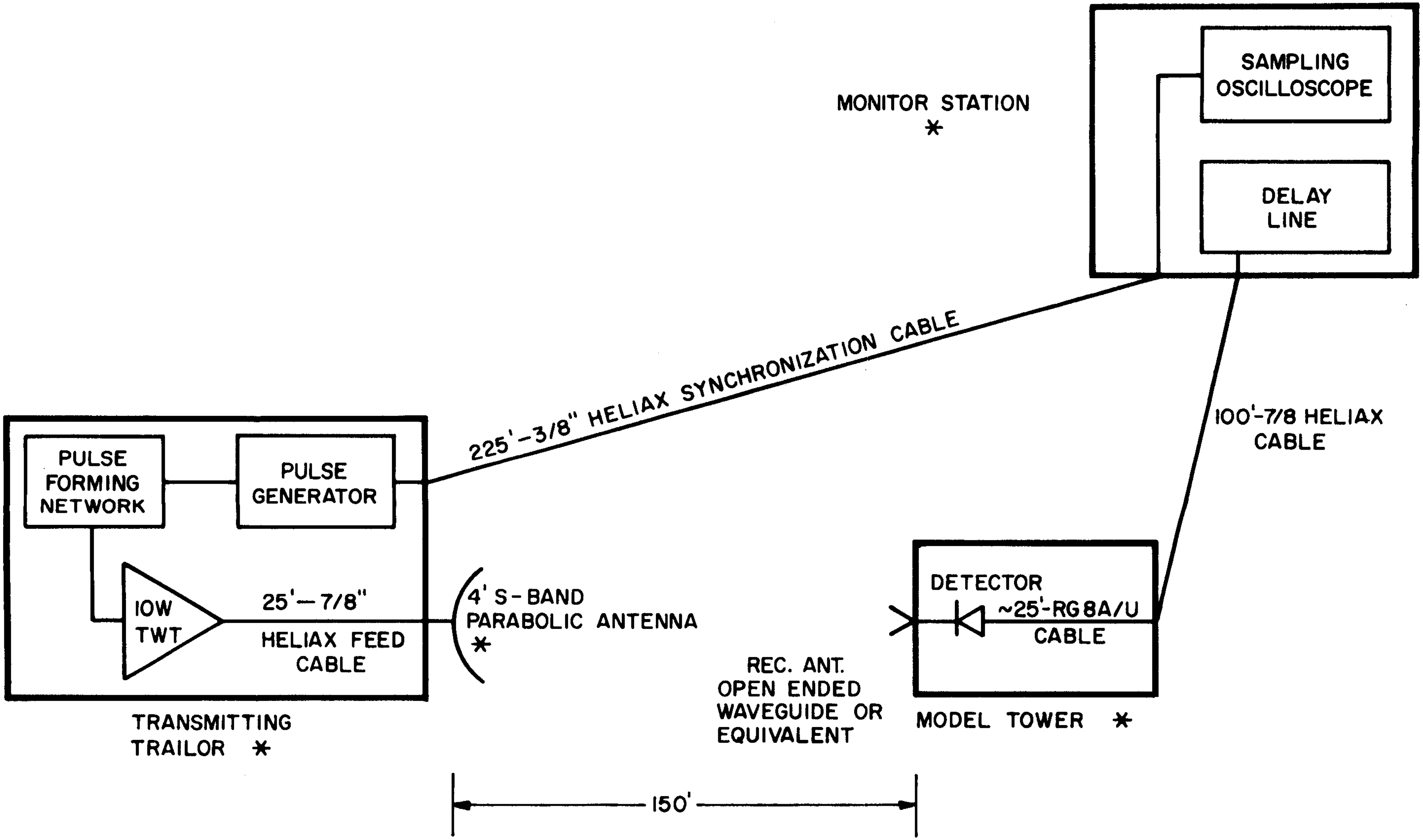
1) Pulse generator, pulse forming network and a 10 W TWT amplifier in the transmitting trailor
2) Open ended waveguide antenna and detector placed on the model tower
3) A delay line and sampling oscilloscope placed in the monitor station
4) Interconnecting cables (RG 8 A/U and Heliax).

For ease of installation the cable terminals have been identified by a number or note describing where they are connected. Three large heliax cables are provided. These are installed as follows:

a) 3/8" heliax cable, 225 feet long installed between transmitting trailor and the monitor station. The pressure gage should be mounted in the transmitter trailor. A short length of RG 8 A/U cable is provided for connection to the "external trigger output - 50 ohm" jack on the pulse generator. The end of the heliax cable in the monitor station is connected to the "trigger in" terminal of the sampling oscilloscope.

b) A 100'7/8" heliax cable is provided to take the detected signal from the model tower to the monitor station. The pressure gage must be located inside of the monitoring building. This end of the cable is connected directly to one end of the delay line. A 25 foot length of RG 8 A/U cable is provided to connect between the end of the heliax cable and the detector mount which is connected to the output of the receive antenna located in the model.

c) A 25' 7/8" heliax cable is to be installed between the 4' parabolic antenna to the equipment inside the transmitting trailor. A short length of RG 8 A/U cable is provided for connecting the heliax cable to the 10 watt TWT amplifier or to other transmitting equipment used on the pattern range.



EQUIPMENT FURNISHED BY MSFC NOTED BY *

FIG. 21–PROPOSED LOCATION OF EQUIPMENT AND CABLING.

d) A RG 8 A/U cable (GR connectors) that is about 3' in length is connected between "50 ohm output" jack and the "Sig. In for Trig. Takeoff" jack. A 13' RG 8 A/U cable (GR connectors) is connected between the "98% Signal Out" jack and the input to the ECI Pulse Shaper (on the back of the unit). The output of the pulse shaper is fed through a short length of RG 8 A/U cable, through a 3.0 db attenuator to the input of the 10 watt TWT amplifier.

e) Two GR to type N (male) adaptors are provided for connections to be made on the back of the pulse generator and the pulse shaper. A type N (female) to type BNC (male) adaptor is provided to connect the 25' RG 8 A/U cable to the detector mount.

f) The probe for one channel of the sampling oscilloscope is connected to the output end on the delay line.

g) The receive antenna (open ended waveguide) is to be mounted on the model tower.

h) The equipment is now ready to be energized. Set the controls on the unit as follows:

Type 110 Pulse Generator:

1. pulse amplitude range switch on "50"
2. pulse amplitude at "0"
3. mode switch "off"
4. energize

Type 110 Trigger Select System:

1. "Takeoff - Ext 50 ohm" switch in "Takeoff" position
2. "External Output-Regeneration" switch in "External Output" position

ECI Pulse Shaper:

1. energize

Alfred 10 w TWT Amplifier:

1. place helix voltage at 1320 volts
2. place grid bias at -250 volts
3. energize

4. monitor the helix current on warm-up, keep the current switch in the "anode current" position during operation

HP Sampling Oscilloscope:

1. energize
2. place time base switch at 10 nsec/cm
3. place time base multiplier on times 1
4. place vertical amplifier on 20 mv/cm.

i) Put the Pulse Generator mode switch in "on" position and increase amplitude to approximately 35 V. Increase the TWT grid bias to zero volts. Adjust the sampling oscilloscope trigger controls and time base controls to obtain pulse on the trace. Adjust the response control as directed in the instruction manual.

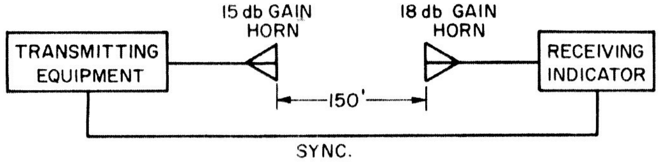
2.2.4 System Evaluation At M.S.F.C.

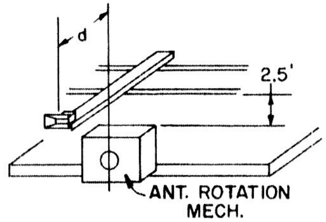
The antenna pattern range test equipment was temporarily installed on the pattern range at M.S.F.C. A permanent installation was not feasible at the time. All components and cables that were supplied as a part of the test set were utilized in the measurements. The equipment setup is shown in Figure 21.

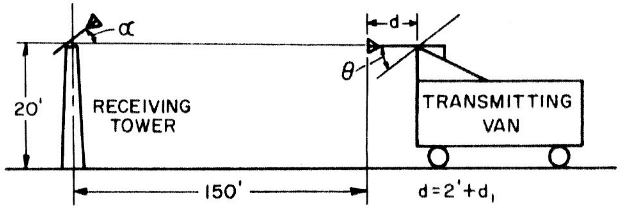
Several measurements were conducted to evaluate the system and these will be described separately.

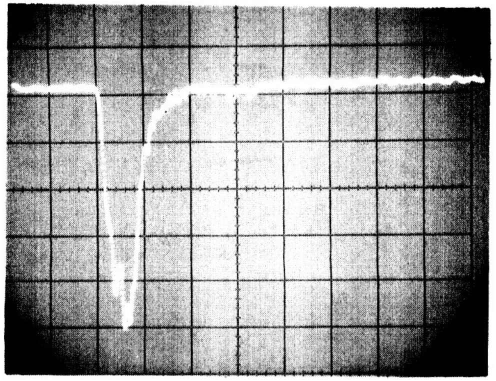
Two pyramidal horns with gains of 15 db and 18 db were used for transmitting and receiving, respectively. The test was to determine if reflection from objects very close to boresight were present. The receive antenna elevation angle was varied above ($+\alpha$) and below ($-\alpha$) boresight. Figure 22 shows no reflections from the ground nor from nearby antenna supports. The pulse width is approximately five nsec wide at a point -20 db from peak.

The second test was to rotate the receive antenna from the boresight position toward the gantry. The identical experimental setup as used in the initial test was utilized for this investigation. Photographs of the sampling oscilloscope display were taken at 0, 30, 60, and 90 degrees of rotation of the receive antenna. At 30 degrees of

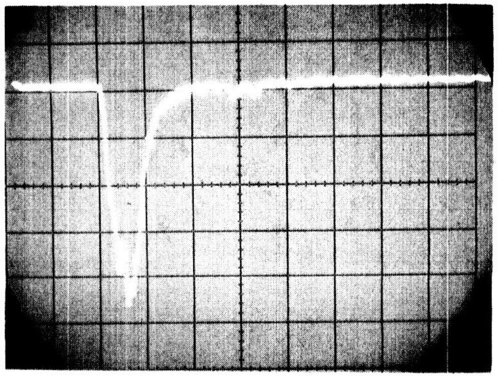




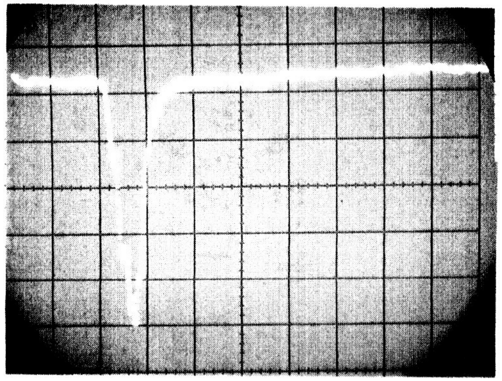




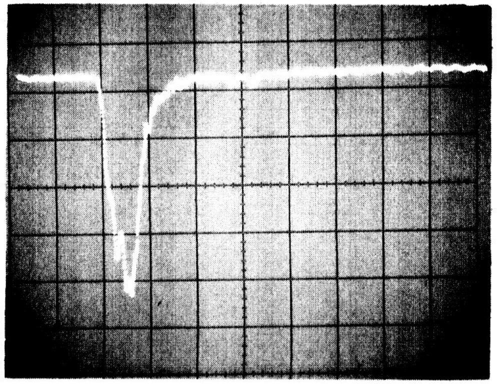
$\alpha = 0°$ $d_1 = 0$
H: 4 nsec/cm V: 6 mv/cm



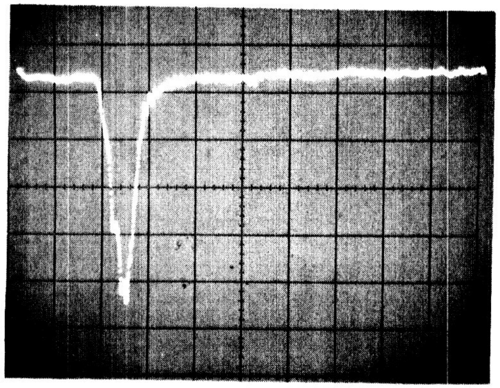
$\alpha = 15°$ $d_1 = 0$
H: 4 nsec/cm V: 6 mv/cm



$\alpha = 30°$ $d_1 = 0$
H: 4 nsec/cm V: 3 mv/cm



$\alpha = -15°$ $d_1 = 0$
H: 4 nsec/cm V: 6 mv/cm



$\alpha = -30°$ $d_1 = 0$
H: 4 nsec/cm V: 3 mv/cm

FIG.22 - TEST RESULTS AT M.S.F.C.

rotation, the boresight pulse is approximately 25 db down on the receive element pattern. In Figure 23, for $\beta = 30^{\circ}$, a small deflection occurs at this position. At angles greater than 30°, only reflected signals would be expected.

In the third test, the receive antenna was on boresight and the transmit antenna was positioned at $d = 2' + d_1$ (see Figure 24). Negligible difference in the pulse shape occurs as the antenna was moved back closer to the supporting structure. This indicates that the reflections from the transmit antenna supports, trailor, and associated equipment were down greater than 20 db (i.e., provided these reflections were from points on a path greater than 4 nsec from boresight).

The fourth test was with the transmit antenna elevation angle varied from 0 to -30° ($\theta = 0^{\circ}, -15^{\circ}, -30^{\circ}$) while the receive antenna remained on boresight. This measurement was to determine if the portable hydraulic ladder located in front of the transmit position was affecting the pattern.

The photographs in Figure 25 show that the reflections were down at least 20 db from boresight. The bottom photograph in Figure 25 was taken with the transmit horn mounted on the antenna rotating mechanism and on boresight. There was essentially no difference in the pulse shape.

The fifth measurement was with the horns replaced by the 29 db parabolic dish for transmitting and an open ended waveguide element for receiving. Figure 26 shows the boresight condition with a total pulse height of 30 mv. The pulse was approximately 5 nsec wide at the -20 db level (3 mv). It was not possible to identify any reflections with the antennas in this position.

A demonstration of the system was given to the M.S.F.C. personnel at the test site and a few tests were conducted by them. These tests included detecting perturbations purposely placed on the range. One of these was to place an aluminum plate on the side

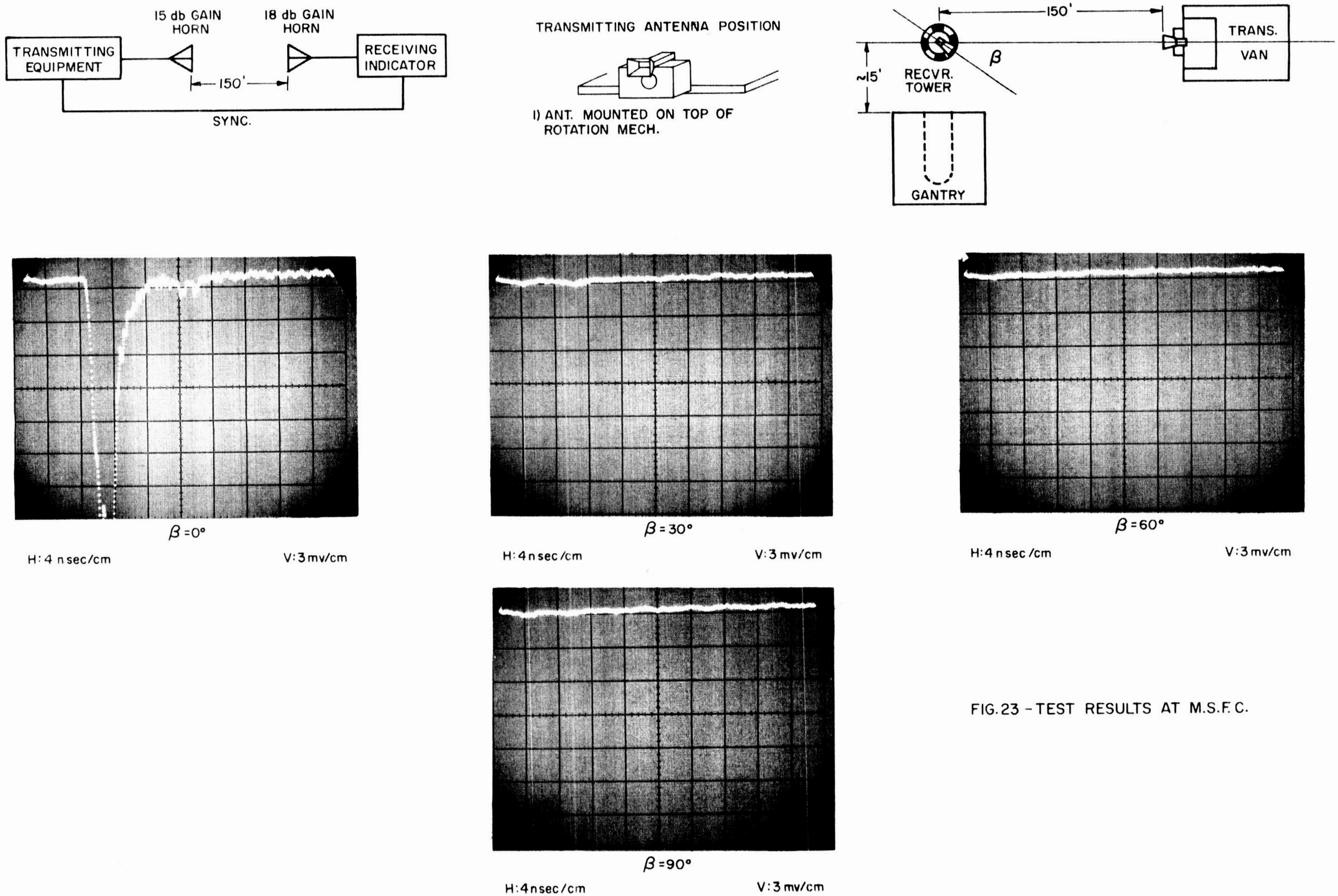


FIG. 23 - TEST RESULTS AT M.S.F.C.

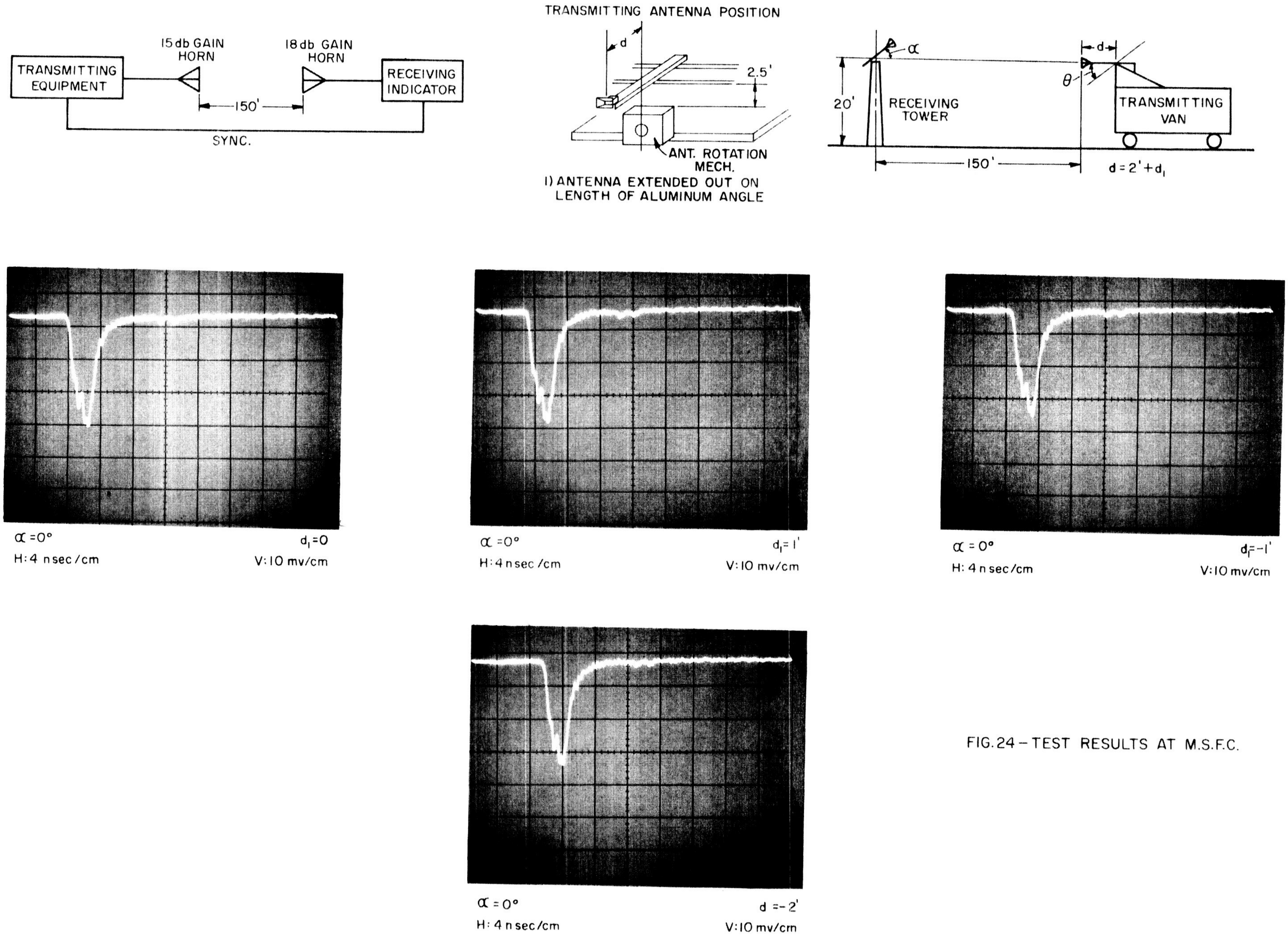
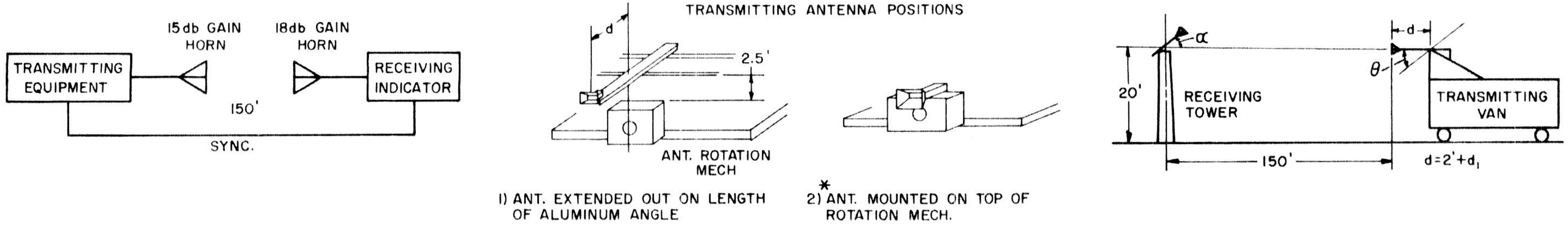
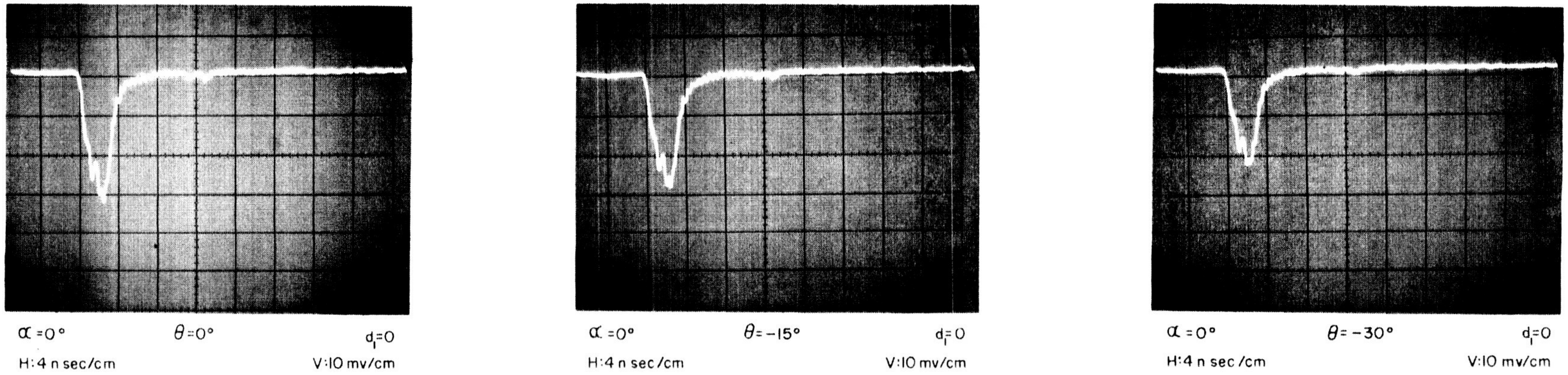


FIG. 24 – TEST RESULTS AT M.S.F.C.





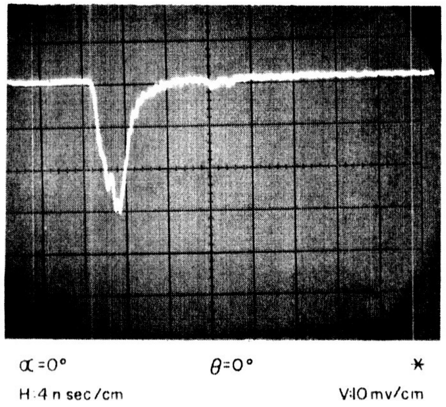


FIG. 25 - TEST RESULTS AT M.S.F.C.

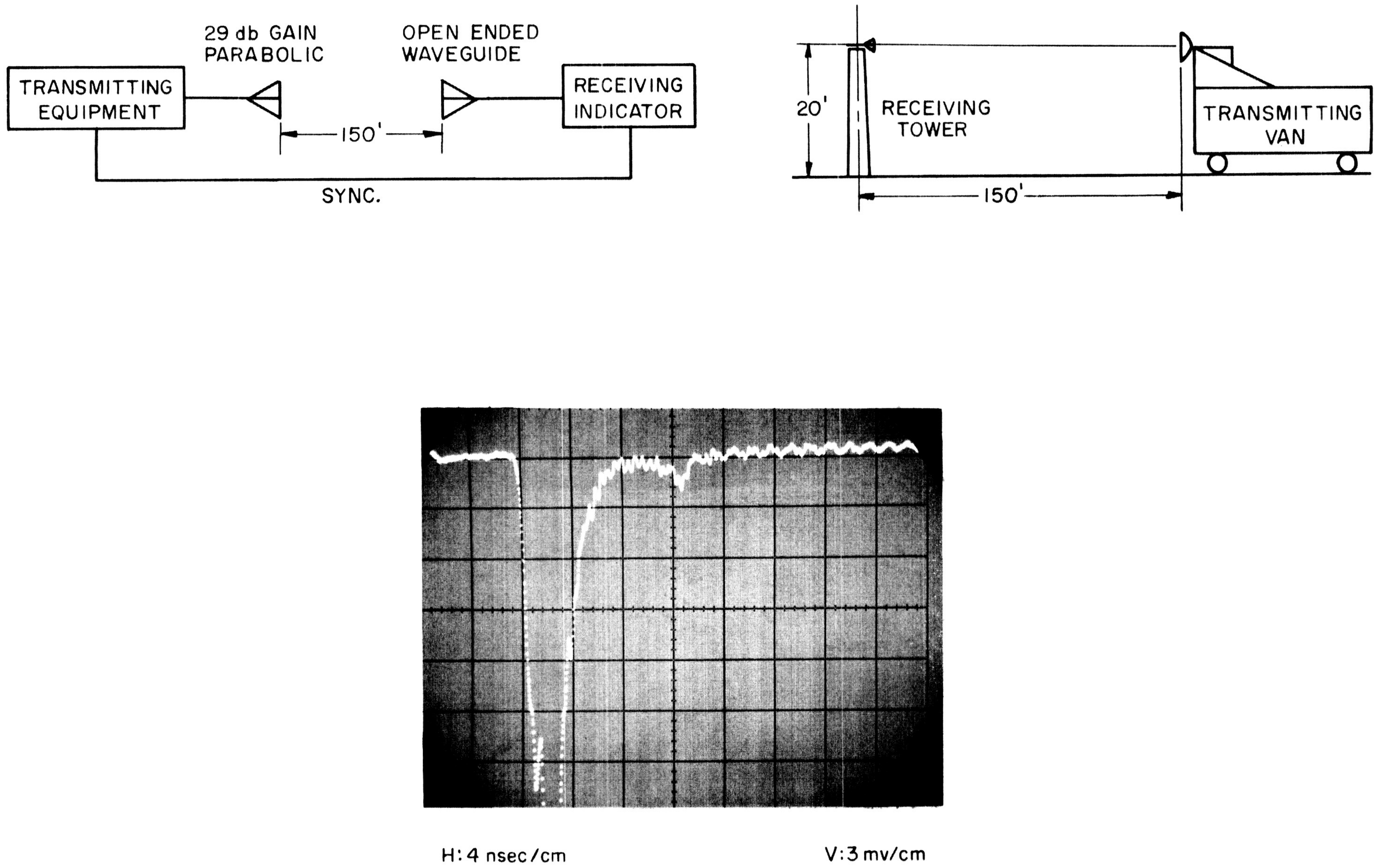


FIG. 26 – TEST RESULTS AT M.S.F.C.

of the receive support tower and to mount the receive antenna on the gantry. The gantry was moved back a few yards and the support tower was rotated until detection. Upon removal of the plate, the receive tower signal was not detectable.

With the receive antenna (open ended waveguide) on boresight, the hydraulic ladder was placed at mid point on the pattern range but it was not detected. This is due to the narrow beamwidth of the transmitting element and that the angle of scattering from the ladder may not have been proper for detection.

Upon completion of the demonstration, further instructions were presented on the system operation.

3. CONCLUSIONS AND RECOMMENDATIONS

The system as demonstrated at M.S.F.C. satisfied the requirements for a bistatic radar test set to resolve antenna pattern range ambiguities as set forth in the contract.

Improvement in system sensitivity may be obtained by amplifying the rf prior to detection. A suitable amplifier is a low noise S-band TWT which is available in a small package. Light weight units are available such as the Watkins Johnson WJ 269. The WJ 269 has a 28 db gain and a maximum rated output of -5 dbm. The detector has a minimum detectable signal level of -33 dbm.

The maximum signal input to the TWT without saturation is approximately -33 dbm. Signals that saturate the unit create a problem in recovery times therefore it is desirable to keep the boresight pulse below the saturation level. Reflections 28 db below the boresight pulse would then be at the minimum detectable signal (-61 dbm). The transmitted power would have to be reduced by reducing the pulse generator voltage amplitude and adjusting the 10 w TWT controls to minimize saturation of the receive TWT. A diagram of respective power levels is shown in Figure 27.

A high gain TWT with an output of +10 dbm would provide a wider dynamic range but small light weight units currently are not available.

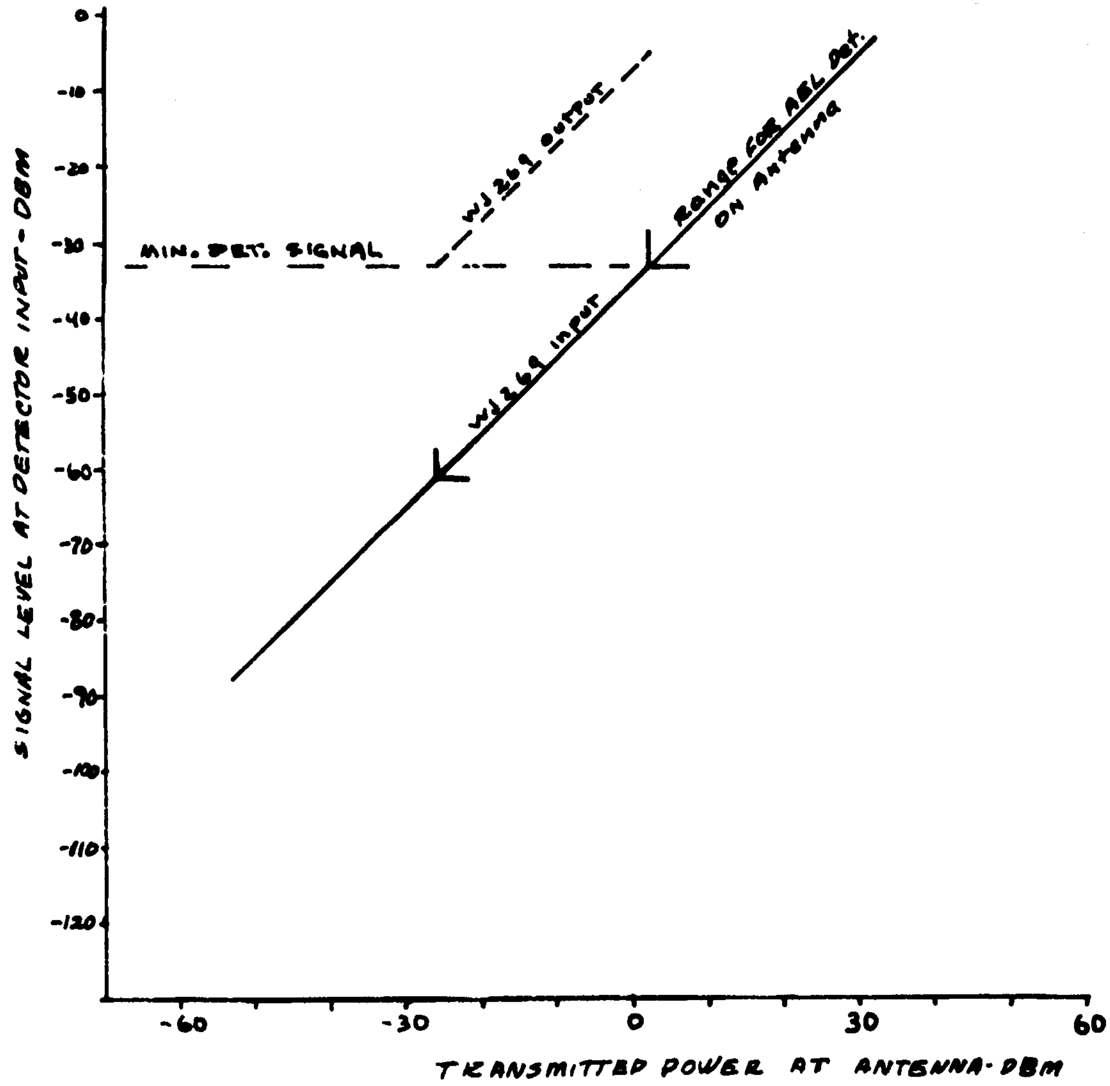


FIG. 27.-RESPECTIVE POWER LEVELS IN SYSTEM
$G_T = 29$ db, $G_R = 0$ db